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MSFC SKYLAB ELECTRICAL POWER SYSTEMS MISSION EVALUATION

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MSFC
SKYLAB
ELECTRICAL POWER SYSTEM
MISSION EVALUATION REPORT

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DEFINITIONS

Terminologies of the Electrical System and Mission Support Activities are described to establish a single meaning for key words and phrases used herein.

Mission Operations Related Terminologies

Mission Support Phases

Pre-Mission - Includes all activities prior to launch, such as planning, preparation, training, familiarization briefings, coordination meetings, mission simulations, and prelaunch test and checkout.

Mission - Includes all activities from launch of the Skylab (SL-1) to splashdown of the SL-4. Both manned and unmanned orbital phases are included.

Post-Mission - Includes all activities following splashdown of the SL-2, SL-3, and SL-4; primarily post-flight data analysis and evaluation report inputs.

Mission Evaluation - Includes

> The significant event events of each SL mission with regard to anomalies, trends, problems, and their solutions, and
>
> System performance.

Real-Time Data - All TM data transmitted from Skylab to HOSC via Mission Control Center (MCC) without being processed (except for compression) in near real-time. This is also referred to as "Operations compressed data". In addition, Skylab data transmitted from Kennedy Space Center (KSC) to HOSC via the DATA-CORE is in real-time.

Non-Real-Time Data - All data from any source which has been processed (i.e., taped, computed, converted) prior to receipt at HOSC; includes all Data Digital Tape (ADDT), Auxiliary Storage and Playback (ASAP), Mission Operations Planning System (MOPS), and AM Recorded data.

Anomaly - Any off-normal operation of the system, subsystem or component that occurs randomly and is not repeatable.

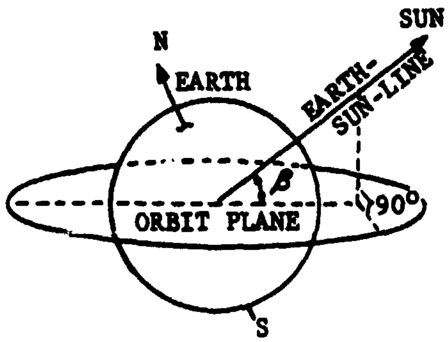
Malfunction - Any failure of a piece of hardware to function as it should.

Contingency Condition - A condition resulting from one or more component malfunctions that require actions to be taken to either continue or safely terminate the mission.

Flight Controller - A person responsible for monitoring and controlling spacecraft systems via flight control consoles at the MCC at JSC during missions.

Flight Crew - The astronauts manning each Skylab mission constitute the flight crew.

Beta Angle - The angle between the orbital plane and earth-sun line (solar vector) This angle is measured perpendicular to the orbit plane as follows:



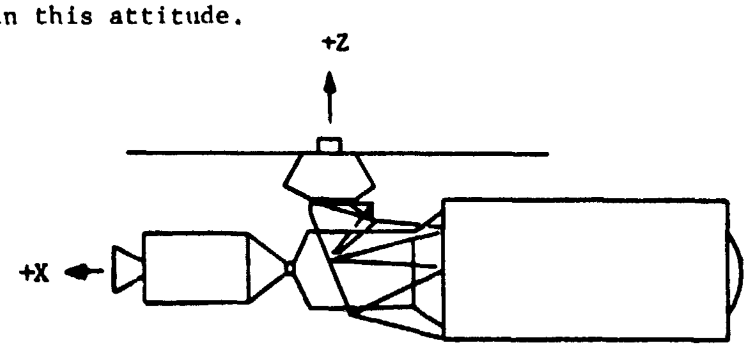
Beta can be expressed in terms of the following angles:

- θ : Inclination of the orbit plane to the ecliptic plane.
- ε : Right ascension of the incident rays of the sun in the plane of the ecliptic (dependent on launch date).
- ε_o: Right ascension of the ascending mode of the orbit in the plane of the ecliptic.

Based on these angles, $\beta = -\sin^{-1}[\sin\theta \sin(\varepsilon - \varepsilon_o)]$

When the sun is north of the orbit plane, beta is positive. For a 50-degree orbit inclination, beta ranges between plus and minus 73.5 degrees. This is the definition of Beta Angle used by the EPS team. Other definitions of Beta Angle do exist; these are acceptable for use by other engineering disciplines.

SI Attitude, X-Axis in Orbit Plane (X-IOP) - The principal SWS X-axis is in the orbital plane with the Z-axis co-incident with the sunline. The following diagram shows the axes definitions. The plus Z-axis points directly toward the sun. The major portion of the mission is in this attitude.



Earth Pointing Attitude, Z-LV-E - The SWS X-axis is in the orbital plane with the minus Z-axis pointing toward the center of the earth and the plus X-axis in the direction of the velocity vector. A total of 65 Z-LV-E passes during the planned eight-month mission were baselined.

Integrated System Testing - All multi-module testing at the Manned Spacecraft Operations Building (MSOB), the Vehicle Assembly Building (VAB) or at the launch pad at KSC.

Electrical Systems Terminologies -

Skylab or Cluster EPS - Defined as ATM and AM/OWS EPSs operating in parallel.

ATM EPS - Defined to include the solar array, Charger-Battery-Regulator Modules (CBRM's), power distribution network, and all associated control circuits and devices. The power distribution shall include power feeders, connectors, relays, diodes, fuses, and circuit breakers (on ATM Control and Display (C&D) panel) from:

Solar panel power connected to the CBRM

CBRM to buses 7D10, (7D11) and 7D20, (7D21).

Buses 7D11 and 7D21 to all loads connected to their sub-buses, to the ATM/AM power feeder interface and to the ATM C&D console.

AM/OWS EPS - Defined to include the solar array, Power Conditionong Groups (PCG s), power distribution network, and all associated control circuits and devices. The power distribution shall include power feeders, connectors, relays, diodes, fuses and circuit breakers from:

Solar array modules to PCG s.

PCG s to Regulated Buses.

Regulated buses to all loads connected to their sub-buses and to the ATM/AM and Command Module/MDA (CM/MDA) power feeder interfaces. OWS buses and MDA sub-buses shall be considered sub-buses of the AM/OWS EPS.

Power Distribution Network - Includes all wiring that provides primary Direct Current (DC) power (bus to bus and bus to load) and secondary DC power (e.g., from DC-DC converter to load).

Electrical Network - Includes all wiring between black boxes which are not part of the power distribution network. This includes the signal circuits up to the black box.

Electrical System - Consists of the EPS and the electrical network.

Power Requirement - Power requirement as referred to in this document is the electrical power required by the equipment. This term is synonymous with "load" requirement.

Power Capability - The power capability of the individual power system is the power available at major buses 7D11 and 7D21 in the ATM EPS, Regulated Bus 1 and Regulated Bus 2 in the AM EPS. Power Capability is defined for the SI and Earth pointing attitudes as follows:

SI - Average power per one orbit (i.e., one battery charge/discharge cycle) that does not violate any of the following criteria:

Energy balance condition for each power subsystem in one orbit.

Battery Depth of Discharge (DOD) not more than 30 percent of rated capacity during the orbit.

Maximum load rating of an ATM load regulator of 15.5A (415 watts); Maximum load rating of an AM load regulator of 50A (1,400 watts).

Z-LV - Average power per one Z-LV interval that does not violate any of the following criteria:

> The difference between the highest battery State-of-Charge (SOC) during the SI orbit preceding the Z-LV operation and the lowest SOC through the first subsequent SI orbit shall be less than 50 percent of the rated capacity. (Pre-Mission definition.)
>
> Battery capacity remaining shall be at least 30 percent of the rated capability. (This criteria was dropped for ATM batteries.)

Power Margin - This is the difference between the total equipment load requirement at the bus and the power capability expressed in terms of average power during the orbit. A positive power margin exists when the capability exceeds the power requirement. To determine the power margin, the average load requirement during one orbit must first be determined since the capability value is given in terms of the average per orbit.

Power Sharing - Power sharing is referred to in this document primarily as the amount of power contributed by the ATM and the AM/OWS EPS's at the respective buses when they are operating in parallel. The power sharing is a function of the Regulated Bus Voltage setting, load condition, and the number of CBRM s and PCG s operating.

Energy Balance - An energy balance condition for a solar array battery power system exists when the energy available from the solar array is exactly equal to the energy required by the equipment during the day portion of the orbit and the energy required to fully recharge the batteries that were discharged in the previous night portion of the orbit. The energy balance equation forms the basis for the computation of the power capability and margin for the SI orbit.

Battery DOD - This is the battery capacity removed during a certain time period, expressed in absolute units (ampere-hours) or in percentage. When expressed in percent, it is the ratio of ampere-hours removed to the rated ampere-hours multiplied by 100.

Battery State of Charge (SOC) - This is defined in terms of the actual output capacity available, and is expressed in percent of the rated capacity or in ampere-hours.

Solar Array Incident Angle - This is the angle betweer the sun line and the normal to the plane of the solar panel.

ABBREVIATIONS

A, AMP	Ampere
AD	Auto-Disconnect
ADDT	All Digital Data Tape
Ag Ti	Silver Titanium
Ag Zn	Silver Zinc
AHM	Ampere-Hour Meter
ALT	Altitude
AM	Airlock Module
AMP-HRS, AH	Ampere Hours
APCS	Attitude and Pointing Control System
AR	Action Request
ASAP	Auxiliary Storage and Playback
AT	Acceptance Testing
ATM	Apollo Telescope Mount
ATP	Acceptance Test Procedure
AVE	Average
AWG	American Wire Gauge
β	Beta
BAT	Battery
BED	Box External Data
BID	Box Internal Data
BOM	Beginning of Mission
BV_{CEO}	Collector to Emitter Output Voltage
C	Charge
°C	Degrees Centigrade
CB	Circuit Breaker
CBRM	Charger/Battery/Regulator Module
CCB	Configuration Control Board
CD	Countdown
CDF	Contained Detonating Fuse
C&D	Control and Display
C&W	Caution and Warning
CDR	Critical Design Review
CEI	Contract End Item
CHGR	Charger
CM	Command Module
cm	Centimeter
CMD	Command
CMG	Control Moment Gyro
CoAS	Crew Optical Alignment Sight
C/O	Checkout
con't	Continued
CRS	Cluster Requirements Specification
CSDR	Cluster System Design Review
CSM	Command and Service Module
CY	Calendar Year

ABBREVIATIONS (Continued)

DA	Deployment Assembly
DAS	Data Acquisition System
DC	Direct Current
DCR	Design Certification Review
DCS	Digital Command System
DEG	Degrees
DOD	Depth of Discharge
EBW	Exploding Bridgewire
ED	Engineering Document
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EO	Engineering Order
EOM	End of Mission
EPEA	Experiment Pointing Electronics Assembly
EPS	Electrical Power System
EPSTE	Electrical Power System Telemetry Evaluation
EREP	Earth Resources Experiment Package
ESE	Electrical Support Equipment
EVA	Extra-Vehicular Activity
°F	Degrees Fahrenheit
FAS	Fixed Airlock Shroud
FLT	Flight
FRR	Flight Readiness Review
FSA	Fire Sensor Assembly
FSCP	Fire Sensor Control Panel
FU	Firing Unit
FWD	Forward
G	Gravity
GET	Ground Elapsed Time
GMT	Greenwich Mean Time
GND	Ground
GOSS	Ground Operational Support System
GSFC	Goddard Space Flight Center
HI	High
HLAA	High Level Audio Amplifier
HOSC	Huntsville Operations Support Center
HR	Hour
HTR	Heater
I	Current
ICD	Interface Control Document
i.e.	For example
IF	Interface

ABBREVIATIONS (Continued)

I&C	Instrumentation and Communication
ILCA	Inverter/Lighting Control Assembly
IR	Infrared
IU	Instrument Unit
Jett	Jettison
JOP	Joint Observing Program
JSC	Johnson Space Center
k	Kilo
°K	Degrees Kelvin
KSC	Kennedy Space Center
LEM	Lunar Excursion Module
LV	Launch Vehicle
M	Meter
mA	Milliampere
MAN	Manned
MAR	Mission Action Request
MAX	Maximum
MCC	Mission Control Center
MDA	Multiple Docking Adapter
MGR	Manager
MIL	One-thousandth of an inch
MIN	Minute
MO	Mission Operations
MOPS	Mission Operations Planning System
MSFC	Marshall Space Flight Center
MSG	Mission Support Group
MSGL	Mission Support Group Leader
MSOB	Manned Spacecraft Operations Building
mS	Milliseconds
MUX	Multiplexer
mV	Millivolts
mW	Milliwatt
η	Efficiency
NASA	National Aeronautics and Space Administration
NiCd	Nickel Cadmium
nMi	Nautical Miles
No.	Number
OA	Orbital Assembly (AM, MDA, ATM, OWS)
OAT	Orbital Assembly Test
OCV	Open Circuit Voltage

ODB	Operational Data Book
O&C	Operations and Checkout
	Ohm
O/P	Output
OPS	Operations
OWS	Orbital Workshop
P	Pressure
PAD	Power Allocation Document
PCG	Power Conditioning Group
PDR	Preliminary Design Review
PIA	Preinstallation Acceptance
PM	Program Management
PMC	Post Manufacturing Checkout
PNL	Panel
POT	Potentiometer
PPO_2	Partial Pressure of Oxygen
$PPCO_2$	Partial Pressure of Carbon Dioxide
PRE-FLT	Pre-Flight
PREP	Preparations
PRIM	Primary
PROC	Procedure
PS	Payload Shroud
PSI	Pounds per Square Inch
PWM	Pulse Width Modulator
PWR	Power
QTY	Quantity
QUAL	Qualification
R	Resistance
RAD	Radiation Absorption Dose
RCS	Reaction Control System
REG	Regulator
REP	Representative
RET	Return
RF	Recharge Fraction
rf	Radio Frequency
RFI	Radio Frequency Interference
Rs	Refrigeration Subsystem
RTG	Radio-Isotope Thermoelectric Generator
SAA	South Atlantic Anomaly
SA or S/A	Solar Array
SAG	Solar Array Group
SAL	Scientific Airlock

ABBREVIATIONS (Continued)

SAS	Solar Array System
SAWS	Solar Array Wing Simulator
SCA	Sneak Circuit Analysis
SCD	Specification Control Drawing
SCPS	Skylab Cluster Power Simulator
SCR	Silicon Control Rectifier
S&E	Science and Engineering
SEC	Second
SEDR	Service Engineering Data Reports
SEPSA	Skylab Electrical Power System Analysis
SI	Solar Inertial
SIA	Speaker Intercom Assembly
SIG	Signal
SL	Skylab
SIT	Systems Interface Test
S-IVB	Saturn V - Third Stage
S/N	Serial Number
SOC	State-of-Charge
SOCAR	Systems/Operations Compatibility Assessment Review
SP	Solar Panel
SPEC	Specification
SPG	Single Point Ground
SST	Spacecraft System Testing
STDN	Spacecraft Tracking and Data Network
STS	Structural Transition Section
STU	Skylab Test Unit
SUS	Suit Umbilical System
SW	Switch
SWS	Saturn Workshop
SYS	System
TACS	Thruster Attitude Control System
TB	Terminal Board
TCS	Thermal Control System
TCSRD	Test and Checkout Specification Requirement Document
TEMP, T	Temperature
TIR	Total Indicator Reading
TM, T/M	Telemetry
TV	Television
T-V	Thermal Vacuum
T_x	Time, Reference Signal
UNMAN	Unmanned
UMB	Umbilical
UV	Ulatraviolet
µA	Microampere
U1, U2	Flight and Backup AM

ABBREVIATIONS (Continued)

V	Volts
VAB	Vehicle Assembly Building
VDC	Volts Direct Current
VGP	Vehicle Ground Point
V_{OC}	Open Circuit Voltage
WCIU	Workshop Computer Interface Unit
XFER	Transfer
X-IOP	X Axis in Orbit Plane
X-IOP/Z	X Axis in Orbit Plane/Z Axis Solar Inertial
Z-LV-E	Z-Local Vertical - Earth Pointing Mode
Z-LV-R	Z-Local Vertical - Rendezvous Mode

A. SUMMARY

The Skylab Electrical Power System (EPS) launch configuration consisting of two independent and complementary power generation, storage, control, distribution, and monitor systems was the culmination of a prolonged evolutionary stage. The evolution was prompted by major changes in mission objectives, design requirements, state-of-the-art advances, test results, and crew desires, which were coordinated at NASA Intercenter Electrical Panel meetings, design reviews, SOCARs, DCRs, and FRRs.

The complexity of the EPS imposed the development and use of analytical tools that could rapidly reflect the system configuration as it changed and yield accurate performance predictions. These tools included use of Functional Flow Diagrams, Load Assumptions and Power Allocation Documents and Computer Programs for System Analyses. Contingency analyses performed prior to launch included the possible failure to deploy the OWS Solar Array Wings and thus proved invaluable for quick response to the real-time occurrence.

Pre-Mission Design Verification was conducted at the component, black box, sub-system, system, and flight vehicle levels. Results from this program required some design modifications, performance requirement and prediction up-dating, and gave insight into hardware/system anomalies to be expected in-flight as well as the knowledge of how to overcome, work-around, or repair those conditions. Several contingency procedures were generated, pre-launch, for use, as required, during the mission. During the mission, unexpected anomalies imposed additional ground testing, using back-up hardware and/or the Skylab Cluster Power Simulator (SCPS), to verify analytical conclusions prior to implementation by the flight crew. In some cases the back-up crew verified astronaut ability to accomplish proposed repair procedures.

The Skylab Cluster used the available power to operate, control, and monitor the life-support, housekeeping, experiment, instrumentation and communication, and attitude control systems. All electrical power for Skylab was generated directly from the sun by photovoltaic solar arrays. An exception was the CSM which was powered by fuel cells until fuel depletion. Nickel-Cadmium batteries stored some of this energy to allow continuous powering of imposed loads during each orbital night. Power distribution and control was by means of a two-wire electrical network which utilized a Single Point Grounding system for the entire Cluster. The two independent power systems, were designed to be operated normally in a paralleled mode. This permitted sharing of power in either direction, and upon fuel cell depletion, either sub-system could supply CSM electrical loads. The sub-system having the highest open-circuit voltage (OCV) supplied the majority of the load. OCV was adjustable within the Airlock EPS.

Pre-Mission predictions for EPS performance required up-dating due to the reduction in AM EPS capability caused by the loss of one OWS Solar Array wing, at launch, and accelerated ATM EPS battery degradation. Several off-normal vehicle attitude maneuvers, imposed for vehicle thermal control until a sun-shield could be manually deployed, severely stressed the ATM EPS hardware. Restricted by debris from the meteoroid shield, OWS wing 1 deployment was not possible, thus power scheduled for loads and for AM battery charging was not available. This condition presented an abnormal storage mode for the AM EPS until the crew of SL-2 cleared the restricting debris and deployed the solar array wing. The decision to parallel the two power systems, proved mission essential. This paralleling provided the necessary EPS flexibility, under a variety of non-scheduled and anomalous operating conditions, and with systems having differing degradation rates, to satisfy all imposed electrical loads and for supporting all imposed maneuvers and operating conditions. Analyses of the data retrieved resulted in gaining significant and valuable EPS engineering knowledge, usable for establishing effective design concepts and requirements for future spacecraft. Although the report is presented in discipline language and is primarily intended for discipline use, the information contained may be useful to designers to whom inter-system effects are important.

B. INTRODUCTION

1. Purpose. This report concludes the analyses of the Electrical Power System, in-orbit, performance. The results are presented in discipline language and are intended for discipline use. However, anyone involved in spacecraft systems will gain useful intelligence and insights, from this report, which are applicable during the establighment of design; concepts, requirements, and constraints for future spacecraft.

2. Scope. Skylab electrical power was supplied by three independent, complementary, power subsystems. This report is limited to two of these, namely, the AM/OWS EPS and the ATM EPS. Discussion of the third (CSM EPS) is beyond the scope of this report.

Skylab is considered an integral laboratory, however, in the interest of emphasizing specific performance characteristics, both Cluster and Module hardware distinct section are included.

Significant concept and requirement evolution, testing, and modifications resulting from tests, are briefly summarized to aid in understanding the launch configuration description and the procedures and performance discussed for in-orbit operation.

Only in-orbit; hardware, operational interfaces, repairs, workarounds, unscheduled and scheduled activities are included under mission performance. Anomalous performance is also treated separately for emphasis and visibility.

Manned operations covered 174 of the total 272 mission days which began May 14, 1973 and ended on February 9, 1974. The three 3-man missions were for 29, 60, and 85 days respectively. Table A details various time references used during the mission, the primary references used throughout this report are DAY (i.e. days from launch of SL-1) and GMT. Figure 6.1 shows the significant events and power profiles for the entire mission.

Detailed event times may be found in the Skylab Mission Events List, 25M00700, available in the MSFC Documentation Repository. Skylab systems evaluation details may be found in the following NASA Technical Memoranda.

TMX-64808	MSFC Skylab Final Program Report
TMX-64809	MSFC Skylab Corollary Experiments Final Technical Report
TMX-64810	MSFC Skylab Airlock Module Final Technical Report
TMX-64811	MSFC Skylab Apollo Telescope Mount Final Technical Report
TMX-64812	MSFC Skylab Multiple Docking Adapter Final Technical Report

TMX-64813	MSFC Skylab Orbital Workshop Final Technical Report
TMX-64814	Skylab Mission Report-Saturn Workshop
TMX-64815	MSFC Skylab Apollo Telescope Mount Summary Mission Report
TMX-64817	MSFC Skylab Attitude and Pointing Control System Mission Evaluation Report
TMX-64819	MSFC Skylab Instrumentation and Communication System Mission Evaluation Report
TMX-64820	MSFC Skylab Corollary Experiments Systems Mission Evaluation Report
TMX-64821	MSFC Skylab Apollo Telescope Mount Experiment Systems Mission Evaluation Report
TMX-64822	MSFC Skylab Thermal & Environmental Control System Mission Evaluation Report
TMX-64823	MSFC Skylab Apollo Telescope Mount Thermal Control System Mission Evaluation Report
TMX-64824	MSFC Skylab Structures and Mechanical Systems Mission Evaluation Report
TMX-64825	MSFC Skylab Crew Systems Mission Evaluation Report
TMX-64826	MSFC Skylab Contamination Control Systems Mission Evaluation Report

DAY	DATE (1973)	DAY OF YEAR	MISSION PERIOD
			(FIRST UNMANNED PERIOD)
1	5-14	134	
2	5-15	135	
3	5-16	136	
4	5-17	137	
5	5-18	138	
6	5-19	139	
7	5-20	140	
8	5-21	141	
9	5-22	142	
10	5-23	143	
11	5-24	144	
			FIRST MANNED PERIOD MISSION DAYS
12	5-25	145	1
13	5-26	146	2
14	5-27	147	3
15	5-28	148	4
16	5-29	149	5
17	5-30	150	6
18	5-31	151	7
19	6-1	152	8
20	6-2	153	9
21	6-3	154	10
22	6-4	155	11
23	6-5	156	12
24	6-6	157	13
25	6-7	158	14
26	6-8	159	15
27	6-9	160	16
28	6-10	161	17
29	6-11	162	18
30	6-12	163	19
31	6-13	164	20
32	6-14	165	21
33	6-15	166	22
34	6-16	167	23
35	6-17	168	24
36	6-18	169	25
37	6-19	170	26
38	6-20	171	27
39	6-21	172	28
40	6-22	173	29
			(SECOND UNMANNED PERIOD)
41	6-23	174	
42	6-24	175	
43	6-25	176	
44	6-26	177	
45	6-27	178	
46	6-28	179	
47	6-29	180	
48	6-30	181	
49	7-1	182	
50	7-2	183	
51	7-3	184	
52	7-4	185	
53	7-5	186	
54	7-6	187	
55	7-7	188	
56	7-8	189	
57	7-9	190	
58	7-10	191	
59	7-11	192	
60	7-12	193	
61	7-13	194	
62	7-14	195	
63	7-15	196	
64	7-16	197	
65	7-17	198	
66	7-18	199	
67	7-19	200	
68	7-20	201	
69	7-21	202	

DAY	DATE (1973)	DAY OF YEAR	MISSION PERIOD
70	7-22	203	
71	7-23	204	
72	7-24	205	
73	7-25	206	
74	7-26	207	
75	7-27	208	
			SECOND MANNED PERIOD MISSION DAYS
76	7-28	209	1
77	7-29	210	2
78	7-30	211	3
79	7-31	212	4
80	8-1	213	5
81	8-2	214	6
82	8-3	215	7
83	8-4	216	8
84	8-5	217	9
85	8-6	218	10
86	8-7	219	11
87	8-8	220	12
88	8-9	221	13
89	8-10	222	14
90	8-11	223	15
91	8-12	224	16
92	8-13	225	17
93	8-14	226	18
94	8-15	227	19
95	8-16	228	20
96	8-17	229	21
97	8-18	230	22
98	8-19	231	23
99	8-20	232	24
100	8-21	233	25
101	8-22	234	26
102	8-23	235	27
103	8-24	236	28
104	8-25	237	29
105	8-26	238	30
106	8-27	239	31
107	8-28	240	32
108	8-29	241	33
109	8-30	242	34
110	8-31	243	35
111	9-1	244	36
112	9-2	245	37
113	9-3	246	38
114	9-4	247	39
115	9-5	248	40
116	9-6	249	41
117	9-7	250	42
118	9-8	251	43
119	9-9	252	44
120	9-10	253	45
121	9-11	254	46
122	9-12	255	47
123	9-13	256	48
124	9-14	257	49
125	9-15	258	50
126	9-16	259	51
127	9-17	260	52
128	9-18	261	53
129	9-19	262	54
130	9-20	263	55
131	9-21	264	56
132	9-22	265	57
133	9-23	266	58
134	9-24	267	59
135	9-25	268	60
136	9-26	269	
137	9-27	270	

DAY	DATE (1973)	DAY OF YEAR	MISSION PERIOD
			(THIRD UNMANNED PERIOD)
138	9-28	271	
139	9-29	272	
140	9-30	273	
141	10-1	274	
142	10-2	275	
143	10-3	276	
144	10-4	277	
145	10-5	278	
146	10-6	279	
147	10-7	280	
148	10-8	281	
149	10-9	282	
150	10-10	283	
151	10-11	284	
152	10-12	285	
153	10-13	286	
154	10-14	287	
155	10-15	288	
156	10-16	289	
157	10-17	290	
158	10-18	291	
159	10-19	292	
160	10-20	293	
161	10-21	294	
162	10-22	295	
163	10-23	296	
164	10-24	297	
165	10-25	298	
166	10-26	299	
167	10-27	300	
168	10-28	301	
169	10-29	302	
170	10-30	303	
171	10-31	304	
172	11-1	305	
173	11-2	306	
174	11-3	307	
175	11-4	308	
176	11-5	309	
177	11-6	310	
178	11-7	311	
179	11-8	312	
180	11-9	313	
181	11-10	314	
182	11-11	315	
183	11-12	316	
184	11-13	317	
185	11-14	318	
186	11-15	319	
			THIRD MANNED PERIOD MISSION DAYS
187	11-16	320	1
188	11-17	321	2
189	11-18	322	3
190	11-19	323	4
191	11-20	324	5
192	11-21	325	6
193	11-22	326	7
194	11-23	327	8
195	11-24	328	9
196	11-25	329	10
197	11-26	330	11
198	11-27	331	12
199	11-28	332	13
200	11-29	333	14
201	11-30	334	15
202	12-1	335	16
203	12-2	336	17
204	12-3	337	18
205	12-4	338	19

DAY	DATE (1973-74)	DAY OF YEAR	MISSION PERIOD
			THIRD MANNED PERIOD MISSION DAYS (CONTINUED)
206	12-5	339	20
207	12-6	340	21
208	12-7	341	22
209	12-8	342	23
210	12-9	343	24
211	12-10	344	25
212	12-11	345	26
213	12-12	346	27
214	12-13	347	28
215	12-14	348	29
216	12-15	349	30
217	12-16	350	31
218	12-17	351	32
219	12-18	352	33
220	12-19	353	34
221	12-20	354	35
222	12-21	355	36
223	12-22	356	37
224	12-23	357	38
225	12-24	358	39
226	12-25	359	40
227	12-26	360	41
228	12-27	361	42
229	12-28	362	43
230	12-29	363	44
231	12-30	364	45
232	12-31	365	46
233	1-1	1	47
234	1-2	2	48
235	1-3	3	49
236	1-4	4	50
237	1-5	5	51
238	1-6	6	52
239	1-7	7	53
240	1-8	8	54
241	1-9	9	55
242	1-10	10	56
243	1-11	11	57
244	1-12	12	58
245	1-13	13	59
246	1-14	14	60
247	1-15	15	61
248	1-16	16	62
249	1-17	17	63
250	1-18	18	64
251	1-19	19	65
252	1-20	20	66
253	1-21	21	67
254	1-22	22	68
255	1-23	23	69
256	1-24	24	70
257	1-25	25	71
258	1-26	26	72
259	1-27	27	73
260	1-28	28	74
261	1-29	29	75
262	1-30	30	76
263	1-31	31	77
264	2-1	32	78
265	2-2	33	79
266	2-3	34	80
267	2-4	35	81
268	2-5	36	82
269	2-6	37	83
270	2-7	38	84
271	2-8	39	85
(FOURTH UNMANNED PERIOD)			
272	2-9	40	86
273	2-10	41	87

Table A Skylab Mission Day Reference Chart

C. DESCRIPTION

1. Design Evolution.

a. Power Generation.

(1) AM OWS. The Airlock Electrical Power System (AM EPS) design evolved from a simple primary battery system to a complex solar array/secondary battery system. This evolution was prompted by changes in mission objectives and design requirements.

Until 1967, all system power after docking was to be derived from the CSM EPS. The AM EPS was required to provide only a minimal amount of power during the initial (pre-docking) mission phase, a period of only 11.5 hours. The AM EPS consisted of silver-zinc primary batteries and a power distribution system.

The mission duration was extended and the sophistication of the Orbital Workshop (OWS) increased to accommodate the growing experiment program. The AM EPS design concept was then changed to a solar array/secondary battery system with silver-zinc primary batteries to be used for pre-activation power only. The first of many concepts had solar arrays mounted on the Airlock. Through the evolutionary design phase, as the power requirements increased, the solar arrays were relocated on the OWS to accommodate the increasing array size. Also, in these early design stages, batteries and power conditioning equipment concepts evolved through a series of trade-off studies. One such study compared both Silver-Cadmium and Nickel-Cadmium batteries. The selection of Nickel-Cadmium was based on the availability of more ground test data and flight history implying less development risk. Several solar array/secondary battery system design were evaluated, with the primary goal of increasing the overall efficiency and reliability of the system. Buck regulation was selected to maximize efficiency, for both the battery charger and voltage regulator. In addition, a peak power tracker was incorporated in the charger to extract maximum array power when demanded by the system. The modular regulator design was selected for both the battery charger and voltage regulator with maximum reliability, high efficiency and redundant control circuitry in mind. When the results of this design approach were established, the AM EPS consisted of four Power Conditioning Groups (PCGs), each including; a battery charger, a voltage regulator and a 30 cell, 33 ampere-hour Nickel-Cadmium battery. Input power for the PCGs was derived from solar arrays mounted on the OWS. The solar array was an adaptation of an existing Agena design and, in order to achieve the high input voltage required for a buck regulation scheme, the two array modules were to be wired in series.

At this time, the ATM was a free flying vehicle which was to dock with the Skylab during the final manned mission. In the earlier missions, it was planned to fly the cluster in a gravity gradient attitude with the vehicle X-axis along the local vertical. After the ATM had docked, the attitude was to be solar inertial. While in the gravity gradient attitude, it was planned to have an articulated solar array for solar pointing to maximize PCG input power.

Power requirements continued to increase thus imposing both a larger solar array and the expansion of the number of AM PCGs first to six and finally to eight. Reduction of pre-activation load requirements coupled with the increased available Nickel-Cadmium battery energy from eight units, led to the elimination of AM primary silver-zinc batteries.

At the time PCG component construction was authorized, the design differed from the flight PCGs in the following important respects:

Maximum component voltage ratings for the battery charger and voltage regulator were 110 volts rather than 125 volts.

Only one charger Ampere-Hour Meter (AHM) was available for charge control and TM.

There was no provision for astronaut override of the 100 percent State of Charge (SOC) signal from the AHM.

The AHM return factor and battery trickle charge rate were higher than used in flight chargers.

The discharge limit feature at an AHM SOC of 30% was not incorporated.

The battery case was magnesium and individual cells were of the same design as those flown on Agena.

At this time, the use of ATM solar modules, for both the ATM and OWS solar arrays, to achieve design standardization, was considered desireable. However, since the input voltage requirement for the two power systems was different, it would have been necessary to modify the ATM solar module wiring such that one-half of the series string of one module was wired in series with a second module. Also, thermal analyses of the solar array indicated temperatures that caused the maximum array output voltage to be higher than the 110 volts used for AM PCG design. Design requirements for the AM charger and voltage regulator were changed at this time to accept input voltages of 125 volts maximum (3 sigma, worst case) which provided some design margin. Shortly after this, the so-called, "dry launch" concept was adopted which made the ATM an integral part of the cluster and made the OWS S-IVB a true space laboratory rather than a propulsive stage. Since the ATM attitude control system was capable of holding the cluster in the solar inertial attitude at all times, there was no longer any need for a separate OWS solar array orientation system and the articulation requirement was deleted. Analysis indicated a power margin for ATM which was considerably larger than expected. Thus, a more flexible cluster power system became feasible. A concept of AM/ATM power system paralleling was adopted as it provided better interface voltage regulation at the CSM.

A solar array was later conceived, for the OWS, which was specifically to be used with the AM PCGs as an integrated power system. Maximum and minimum voltage and power requirements were deliberately specified to be 1.5 times the ATM module design to minimize the impact on PCG redesign. Based on imposed constraints and requirements, significant trade-offs were made in this area. First, it was desired to maximize the power obtained from the area available and to minimize weight. The 2x4 cm solar cell size, having a 2 ohm-centimeter base resistivity, had a 11.1% AMO, 28°C efficiency and thus proved to be both cost and performance effective from fabrication, assembly, and power standpoints. Other sizes considered were the 2x2 and 2x6 cm sizes. Second, was the decision to use a panel approach. The equivalent of four solar cell modules were contained on one panel substrate, thereby optimizing the useful area and minimizing overall system weight and complexity.

The requirements were evaluated and it was concluded that, (1) SAS power at the end of mission should be specified, (2) on-orbit degradation should be accounted for ($\approx$6%), (3) shadowing by the ATM solar array and the OWS structure should be considered, (4) the 55°C (328°K) array temperature was too low, and should have been around 70°C (343°K), and (5) performance should be specified at the AM/OWS interface. To cope with the potential effects from the ATM solar array and OWS stage shadowing during unconstrained cluster maneuvers, the "single-string" design concept, consisting of four single series strings of 154 solar cells connected in parallel only at their end points, was implemented.

A design-phase trade-off to optimize thermal control paint for the solar panel rear surface resulted in selection of Z-93 to take advantage of its superior absorptivity and emissivity properties. Analysis indicated a panel temperature reduction of about 7°F (power gain of about 250 watts total). This potential gain initially outweighed the historic difficulty in application, maintenance (cleanliness), and repair for this paint. The method used to assure that equal output from 8 arrays was satisfied, was to combine the modules into groups and distribute them across both wings to compensate for the effects of uneven temperature distribution, which influences array output power. Complete interconnect and wiring redundancy was included at that time.

In the process of design evolution, a second Amp-Hour Meter was added to the battery charger to improve reliability. Also, a discharge limit feature was added to provide a signal to the voltage regulator when the AHM computed battery SOC equaled 30%. The voltage regulator reduced its output and effectively removed the associated battery from the bus. This feature was added to prevent inadvertent overloading of any one battery, although intentional deep discharges were still possible by use of over-ride logic circuitry. Both onboard display and ground TM of AHM status was available. Manual override of the 100% SOC signal from the AHM was added to permit continued battery charging at the voltage limit.

Battery thermal gradients observed during cyclic ground testing prompted a redesign of the battery case to aluminum for improved heat transfer to the coldplate. Internal cell changes were incorporated to reduce the probability of cell internal shorts. To further reduce battery operating temperature and therefore improve cyclic life, the coolant loop temperatures were lowered and both AHM return factor and battery trickle charge rate were reduced. The latter necessitated battery charger design changes.

Late incorporation of the Earth Resources Experiment Package (EREP) as part of the MDA equipment added the complication of off-solar inertial pointing to the mission requirements. This imposed a reduction in power capability (due to off-sun pointing) and an increased electrical load. All imposed loads were satisfied, by design, and certified by test data and analysis prior to launch.

(2) ATM. Three types of power sources were originally considered to meet the electrical load requirement: fuel cell, radioisotope thermoelectric generator (RTG), and solar cell array/secondary battery system.

Fuel cell operation had reactant storage limitations and heat removal problems. Power systems of 2 to 4 kw capacity required an active coolant loop to remove the waste heat. Fuel cell systems with proven life capability for an 18-month mission were not available.

The RTG had two prominent limitations: fuel was not available for a large system, and radiation danger to personnel could exist. The RTGs in development at the beginning of the program had maximum power output capabilities of 500 watts with conversion efficiencies of approximately 5 percent. Thermal heating due to this power loss would have demanded active cooling.

A solar cell array sized electrically to two and one-half times the spacecraft load would be required to allow for charging secondary batteries to supply power during earth occultation periods. Solar cells with proven performance and reliability were readily available, and the low earth orbit minimized degradation caused by charged particle bombardment. Solar cells were particularly attractive on sun-oriented missions because of the availability of 90 degree incident solar radiation without ancillary array pointing systems.

The choice of using solar cells for power generators on the ATM evolved early in the program from initial project power conditioning tradeoff studies. Initial ATM Electrical Power System requirements provided for the ATM to power both the LEM ascent stage and ATM systems via 24 solar panels/power modules (CBRM). Further power conditioning studies evaluated the overall system power requirements and a, 20 solar module, panel/power module configuration was considered acceptable.

To obtain the required surface area for mounting the solar cell modules an array of four deployable wing assemblies was selected. The cruciform pattern was chosen to minimize reaction forces during deployment and the wings oriented 45° to the SWS X-axis for minimum shadowing of other SWS areas and to fit the launch configuration packaging envelope.

The final ATM EPS design did not change significantly from its original concept (i.e., the solar array/battery design). The design evolution involved the quantity of charger-battery-regulator-modules (CBRMs) and solar panels, as well as battery design, mission duration and type.

The mission concept began with the ATM as a free-flying vehicle which used the Lunar Excursion Module (LEM) to provide electrical power prior to solar array deployment.

The ATM solar array was designed so that individual panels were connected to each CBRM which were connected in parallel only at the ATM load buses. Two module configurations were used; one used 2x6 cm solar cells with two cells in parallel, the other used 2x2 cm solar cells with six cells in parallel. Both used 10 ohm-centimeter base resistivity cells and had 114 cells in series.

The initial solar wing assembly panel configuration consisted of 6 solar panels. The total 4 wing configuration consisted of 24 solar panels (16 modules/panel) supplying power to 24 separate power modules (CBRMs). Subsequent power requirement versus capability evaluations indicated a need for reduction in the wing assembly panel configuration. First, the number of panels per wing was reduced to five full panels with a total array configuration of 20 panels and 20 CBRMs. Finally, the number of panels per wing was changed to the flight configuration of four full 20 solar cell module panels and an inboard half panel containing 10 solar cell modules for each wing. This configuration was frozen based upon payload shroud size limitations.

Both module types were universally interchangeable on the ATM wings; thus, the solar array consisted of a combination of each type module. Differences in cell size and construction were the result of individual manufacturer preferences. Two different contractors were employed in order to have a backup module supplier should one experience difficulty in satisfying the imposed schedule, considering the large quantity of modules required. Since both designs were acceptable and on schedule, both type modules were used.

Early solar cell module environmental tests established the limitation of a maximum of 114 solar cells connected in series per module arrangement. The tests revealed that at extreme low temperatures, predicted for ATM solar array operations, high module/panel output voltages were experienced. These voltages were in the magnitudes which could damage components (capacitors) within other ATM systems. The solar cell ceries connection limits were set for a maximum panel output of 70-80 volts at the expected orbital low temperature.

Nickel-Cadmium batteries were desirable because of weight, volume, and proven lifetime. Also, existing secondary battery designs already included 20 ampere-hour, 28 volt, Nickel-Cadmium batteries. This was a logical choice because of the relatively low development cost that would be required for this item.

The major spacecraft constraint was the requirement for passive cooling of the power system components. This constraint required that the electronics packages be designed and oriented for maximum heat radiation. The temperature of the package depended upon the available radiating area. High energy conversion efficiencies were necessary to reduce the amount of heat generated.

Other constraints imposed on the power conversion system included minimum weight and volume and no single point failure system features. These constraints, the passive cooling requirements, and the desirability of having the power conditioning electronics as an integral unit with the battery to simplify interconnect problems, suggested the CBRM rationale. Reliability considerations also supported the modular power system approach.

The maximum sustained load for each CBRM was based on the battery ampere-hour rating and the allowable depth of discharge for the batteries to assure sufficient cycle life to meet the mission lifetime requirement. The electrical load requirements and reliability considerations then indicated the number of CBRMs required.

The number of CBRMs required was originally determined to be 24 when the mission requirements were 18 months of operation at 20 percent allowable depth of discharge. Later, when the mission requirements were changed to 2 months of operation at 25 percent allowable depth of discharge, the number of CBRMs required was reduced to 18. An analysis, using the latest data available, showed that 18 CBRMs were still appropriate for the final mission requirements of 8 months of operation at 30 percent depth of discharge (nominal maximum). The quantity of CBRMs also allowed for loss of up to three CBRMs during the mission.

Batteries composed of 20 A-H Ni-Cd cells were chosen because they were the largest capacity available, with proven performance, to satisfy the original mission requirements.

The 24 cell battery size was the result of a tradeoff analysis. The results indicated that using less than 24 cells would; 1) increase the operating range of the load regulator and decrease its operating efficiency and 2) have high line losses for equal power input. Batteries containing more than 24 cells present difficulties, one of which was an aggrevation of cell voltage and capacity mismatch. Mismatch would have been serious if any ATM cell voltage exceeded 1.55 volts.

The 24 cell approach permitted the use of a step-down switching charger which maximized efficiency. The maximum 24 cell battery voltage during charge was approximately 36 volts. A minimum solar array voltage of approximately 38 volts, insured a voltage step-down for cell charging.

Safe, reliable, and effective performance was achieved through the definition and application of cell and battery operational limits for all expected operating conditions. Essentially these limits and control characteristics were subdivided into two areas of battery operation: normal cyclic operation between 0°C and 30°C, and battery limit conditions such as over and under temperature and emergency conditions.

Four types of Ni-Cd cells were investigated at MSFC. The AB09 cell provided only the negative and positive electrodes and did not have auxiliary signal or recombination electrodes. The AB10 cell, in addition to the two main electrodes, contained a third adhydrode electrode which developed an electrical signal that was proportional to the partial pressure of oxygen. Any hydrogen which evolved was not recombined. The AB12 cell contained a precharged negative electrode, a third adhydrode electrode, and a fourth (fuel cell) electrode. A major difference between the AB10 and AB12 type cell was the 20 percent of precharged cadmium plate surface area added in the AB12 cell.

The purpose of precharge, which increased the effective cadmium electrode area, was to maintain the useful battery capacity for longer periods of cyclic operation. The apparent deficiency of oxygen recombination area in the AB12 cell was offset by the fourth electrode which provided rapid recombination of oxygen and hydrogen. The flight type AB12 cell increased the negative/positive ratio from 1.35 to 1.45 and the final configuration (AB12G) had the third electrode relocated to relieve the non-uniform cell plate pressures.

The third electrode of the AB10 cell could have been either a type B or type C. The third electrode for the AB12 cell was a type C. The basic differences of the type B and type C electrodes were as follows:

Itcm	Type B Electrode	Type C Electrode
Nickel substrate	40 square centimeters	10 square centimeters
Catalyst	Platinum	None
Oxygen diffusion barrier	Electrolyte	1/2-mil teflon film pressed into electrode

The diffusion barrier stabilized the third electrode response as a function of life. The catalyst function in the type B electrode was to recombine oxygen with hydrogen. The evolution of cell design to the AB12G cell took place between 1966 and 1972.

b. Power Distribution and Controls.

(1) AM/OWS. The final configuration of the AM/OWS Power Distribution and Control System was the culmination of many design reviews. The following identifies two of the design trade-offs conducted during the conceptual and requirements definition phases of the system design period.

Initially, a trade-off study was performed between a "one-wire" and a "two-wire" system. Based upon flight history and NASA preference, the two-wire single point ground concept was selected. In this concept, all end items were routed back to the power source return and then the power source return was connected to the vehicle structure at a single point.

The parallel feeder concept which connected all of the nine AM supplied feeders electrically together in the OWS to provide a "stiff bus" or one main bus for each of the AM regulator buses was selected. The power was distributed to each end item from one of the stiff buses and for many end items from either bus and included individual protection. One of the basic requirements imposed upon the OWS system was to limit the voltage drop (line loss) from the AM/OWS interface to any OWS end item to 1.5 Vdc (Positive and Return).

A basic constraint upon the initial design (wet workshop) was to use existing qualified hardware. The largest feed through receptacle qualified for the "wet" workshop environment was 12 gauge. Therefore, the parallel conductor concept was selected.

"Utilize existing qualified hardware" was still the theme when the OWS was converted from a "wet" to a "dry" launch configuration. The Power Distribution and Control console for the "wet" workshop consisted of two enclosed "drag-on" panels (one circuit breaker panel and one control and display panel). The panels were to be stowed in the AM for the launch and would be installed on the wall by the crew. The crew would then connect the pre-installed wire harness connectors to the panels.

The conversion from a "wet" to a "dry" workshop resulted in a complete redesign of the Power Distribution and Control Console. All of the system components could now be hard mounted within the OWS prior to launch.

A console was developed within which the system electronic modules, circuit breaker panels, and control and display panels would be installed. However, the "wet" to "dry" conversion also resulted in more systems, and more sophistication. The circuit breakers, switches, and display arrangement were finalized after mid-year 1971.

In addition to the console mounted panels, four (4) "remote" control and display panels were baselined. The "remote" panels provided local crew control of functions which would be cycled many times during the mission. By providing the controls in the area of usage, traffic to and from the power distribution and control console was considerably reduced.

The original OWS internal wire harness installations concept was to route wiring in as many "hidden" areas as possible to preclude crew contact. Lightweight, protective covers were to be used in areas where it was impossible to "hide" the wiring. These covers would utilize the same pickup points as the clamps for attaching the wiring. The cable routing allowed for physical separation required to maintain EMI control.

After MSFC-SPEC-101A (flammability) was imposed as a requirement, much effort was expended to investigate and evaluate available materials and methods to meet the requirements. This effort included determining the:

Availability of new materials for connector sealing grommets, wire insulation, and clamp cushions;

Available materials for wrapping or enclosing the wire harness and attach clamps;

Methods of protecting the wire harness if suitable insulation materials were unavailable;

Effects of the above approaches on engineering design, manufacturing operations, and schedules.

The resulting flammability and physical protection offered two major advantages. One was better EMI control of the wire harnesses through the use of a continuous metallic barrier afforded by a compartmentized trough. Another was the reduction in the number of routing paths and attach points that would be required in the tank wall insulation.

The number and location of the utility outlets and extension cables was baselined as a function of the crew system reviews. In general, they were located by anticipated/planned usage of the portable equipment (vacuum cleaner, fans, lights, cameras).

The basic design concept for the "wet" OWS was that all wire harnesses would be pre-installed and that all electronic equipment which could not withstand the liquid hydrogen cryogenic temperature environment would be crew installed items. The "drag-in" concept coupled with a potential hazardous atmosphere dictated the use of a connector that provided:

Ease of operation:

Could be operated (connected/disconnected) with one gloved hand under zero-G conditions.

Safety:

Precluded hazardous condition due to arcing when connected/disconnected under load.

Basic requirements for conversion from "wet" to a "dry" OWS were to utilize all applicable "wet" hardware. Therefore, the "dry" OWS retained the "wet" zero-G connector for those end-items which would still require the crew to connect/disconnect.

A worst case voltage drop analysis was performed on all MDA wiring. The analysis indicated the need to increase the number of wires from the AM transfer bus to the CSM/MDA interface to meet the minimum requirement of 27.4 volts at the interface.

The following circuit modifications were implemented:

Wires from the CSM/MDA to the AM transfer bus were increased from 5 to 10, #10 AWG, on each positive bus and from 8 to 18, #10 AWG, on the return bus in the AM.

Wires from the AM to CSM/MDA were increased from 5 to 10, #12 AWG, on each positive bus and from 8 to 18, #12 AWG, on the return bus in the MDA.

A drag through cable was provided to supplement the additional bus wiring. This cable also provided a redundant power transfer connector at the CSM/MDA interface.

(2) ATM. Early in the program the decision was made to have a two-wire system for power distribution and load circuitry employing separate wiring for power feeder and power returns. Distribution of power to ATM loads was accomplished with two positive, isolated, buses each routed through separate connectors, where practical. The ATM return bus was referenced to the structure at the cluster single point ground. Positive polarity lines of the distribution system wiring were protected with circuit breakers or fuses.

The ATM C&D console design concepts evolved through many stages, each constrained by specific envelope, hardware and operational requirements. In the initial stages, design concepts were based upon the fact that solar experimentation was to be controlled by two crewmen stationed in the flight cabin of the LEM. Although the major experiment controls and displays were essentially the same as those of the flight unit, the console configuration was considerably different. All experiment common controls and displays were functionally grouped and contained on a separate panel located and arranged to accommodate an operator in an erect position. The ATM C&D station was defined based on available and extremely limited LEM tunnel space. Console design and operational requirements imposed by the ATM experiments and supporting subsystems were considered secondary. The decision to launch the Saturn V "Dry" Workshop configuration eliminated the requirement for the LEM. The existing console was mounted internal to the MDA. A basic constraint was to use existing qualified hardware due to cost and schedule constraints. Thus, no major redesign of the console was authorized, and the ATM C&D console, as initially designed for LEM compatibility and configuration, was relocated to the MDA.

An additional design problem occurred when the ATM C&D console was removed from the LEM. The AC power necessary for console lighting had been provided by the LEM. An adaptation of the existing LEM-Inverter/Lighting Control Assembly (I/LCA) requirements was used in the MDA design.

A detailed thermal analysis of the I-LCA and the MDA internal mounted equipment indicated the requirement to relocate, and actively heat it, on the MDA external structure.

The fundamental design goal remained unaltered from the concept phase through fabrication to provide a C&D interface sufficient for crew participation in the collection and maintenance of solar experimentation. Selected astronauts were given an opportunity to impose their preference as to switch location and nomenclature. The final arrangement was agreed upon during astronaut review meetings.

The CBRM power sharing scheme was a new and unique technology application. Analyses made early in the ATM program indicated that the electrical power system effectiveness could be increased by up to 25% if a reliable power sharing scheme could be developed to assure that all batteries shared power equal.. The resulting circuit, which had a redundant master control that automatically demanded equal current from all on-line regulators, was a departure from previous designs and fulfilled the system requirements completely. The master/slave principle normally used for this purpose in ground applications was not applicable to flight since its reliability depended on the reliability of the master (a CBRM), and thus would be single failure point in the system.

The power transfer distributor, main power distributor and the auxiliary power distributor used a Deutsch integrated termination system instead of a solder pin termination system. A crimp-type contact was used by inserting it into a sealed termination that required no soldering, wrapping, or splicing, and was easy to maintain. These terminations were modular in design, fit into a compact frame and were arranged in various bus configurations which could accommodate wire sizes from 12 AWG to 26 AWG. When inserted, the contacts were locked in place and were environmentally protected.

After the conversion to the "Dry" Workshop concept, due to the cluster load distribution, the available power margin on the ATM was found to be considerably larger than that of the AM. In order to provide a more flexible cluster power system, and to provide better interface voltage regulation at the CSM interface, the AM and ATM power system paralleling concept was approved.

c. Cluster. The Skylab program involved three NASA Centers, five prime hardware contractors, several integration contractors and numerous subcontractors and vendors. To insure the success of the Skylab program, it was necessary that a continuous interchange of design and performance data flow among the numerous organizations involved and that a clear understanding of the impact of systems design goals and operational constraints be established and reviewed by all the organizations. To create a vehicle for dispersion of data and dissemination of electrical power system performance predictions and operational procedures the Intercenter Electrical Panel was constituted. Co-chairmen from each NASA center were named to coordinate the effort.

Originally the Intercenter Electrical Panel was Scheduled to meet quarterly, rotating the meeting locations among the three NASA centers. The attendance for each meeting was determined by the co-chairmen after the subjects to be reviewed were established. A number of permanent action items were established for presentation at each meeting including the following:

Report on the status of Cluster Electrical Power System Performance Analysis.

Report the predicted load profile for each Skylab mission.

Review the status of the component load requirements per the module Power Allocation Documents.

Review the operational sequencing of components per the mission sequence documents and the electrical load assumptions document.

Review the status of level A ICDs.

Additional items for review were suggested by the panel co-chairmen prior to each meeting and a presentation was prepared by the appropriate organization.

The predicted performance of the electrical power systems was reviewed at each panel meeting to insure that the stated capability was adequate to support the missions identified in the flight plans. The predicted performance was given both for the solar inertial mode and the various off-nominal pointing modes identified. Since the cluster power system was required to provide power to the CSM after depletion of the CSM Fuel Cells, it was necessary that both MSFC and JSC have a clear understanding of both the CSM and the cluster power systems. During initiation and termination of cluster power transfer to the CSM, the two systems operated, momentarily, in parallel. The dynamics of each power system were presented in the Intercenter Electrical Panel meetings for review by all affected organizations.

Some of the dynamic characteristics that were reviewed were the source impedance of each power source; the transient response of the system caused by significant load changes, and the voltage-current characteristics of the power source as reflected on the system load buses. The studies resulting from presentations at the panel meetings revealed that the power systems involved were compatible and could be operated in parallel without degradation of power system performance.

The power system operational requirements were specified in the Cluster Requirements Specification, RS003M00003. Many of these requirements were determined by the Intercenter Electrical Panel and the inputs were submitted for approval. The panel reviewed the interface voltage requirement between the power source and the cluster modules and components. A maximum allowable voltage drop was established and the cabling design was reviewed by the panel to insure that the network design would meet the requirement. Since the electrical power system design requirements specified a two wire system using a single ground point, the return of fault currents to the single ground point was reviewed and the maximum fault current value was established to be used in design of the return paths. All components which violated the two-wire system and used the structure for a return path were identified and reviewed by the panel for impact. Upon approval, the component deviation was documented in the Appendix to the Cluster Requirement Specification.

Items involving the flight crew, such as the design and layout of controls and displays, were reviewed by the astronaut assigned to represent the crew on the electrical panel. Suggestions for panel redesign or nomenclature changes were directed to the module contractors for incorporation. Of special importance to the crew were the emergency power disconnect circuits required to remove all power in the case of an anomaly such as a fire. Several revisions were made to these circuits as a result of the panel meeting reviews.

Since the operation of the EREP experiments involved a peak electrical load requirement during periods of reduced power system capability due to off-nominal pointing, the Intercenter Electrical Panel reviewed the EREP requirements at each meeting. In addition to the power system output capability, the voltage drop to each EREP component was carefully analyzed and the interaction between the EREP operation and related subsystems was studied. As a result of those studies the maximum data-take duration and the location of the data-take in the orbit were specified in the Cluster Requirements Specification.

Numerous other subjects of interest to the design and performance evaluation of the electrical systems were reviewed. Such items as corona, electrical bonding, and lightning protection were reviewed, in detail, to insure that power system design would support the planned Skylab missions without undue operational or procedural constraints.

As the design of the electrical power system evolved toward the final flight configuration a series of reviews were identified by the Skylab Program Management which culminated in the certification of the electrical power system. The Intercenter Electrical Panel continued to function through these reviews to certify the design and performance of the system.

Preliminary Design Reviews and Critical Design Reviews were held for each module. Individual members of the electrical panel participated in the electrical section of these reviews although the Intercenter Electrical Panel did not function as a unit. The action items from these design reviews were reviewed at a subsequent panel meeting to insure that all items requiring panel action or cognizance were properly noted. The first cluster level review was the Cluster Systems Design Review (CSDR) in December 1969.

The CSDR resulted in three significant action items related to the electrical power system operation. Back-up commands from the AM command system were added for both ATM and ATM Solar Array Deployment. These commands provided a redundant system for increased deployment reliability of the Solar Array system.

The decision to operate the ATM and AM electrical power systems in parallel as the normal operational mode was made during the CSDR review of the predicted power system performance. Operating the power systems in parallel permitted the total power available to be used as required to supply loads anywhere in the cluster or to the CSM. The use of the total available power was thus optimized and the impact of power system management on mission planning and crew activity was minimized. Figure 1.1 shows the orbital average load prediction history from 1967 through launch.

From 1967 through 1969, a major attempt to lower the orbital average load requirement was made. Seven hundred and fifty watts were subtracted by lowering the planned usage times and duty cycles of equipment. The 666 watt increase in mid-1969 was the preliminary "dry" workshop load increase. The orbital average load remained essentially unchanged until 1971 when crew timelines began to be written, and hardware testing, to determine actual connected loads, was in progress. The final changes, in late 1972, were caused by a redefinition of heater duty cycles.

The third significant CSDR action item baselined the average and maximum power transfer to the CSM. The maximum power transfer to the CSM was baselined as 1000 watts per each transfer circuit or 2000 watts total. The average power was specified to be 1100 watts. These power values received concurrence by MSFC and JSC panel members and were submitted to the custodian for the Cluster Requirements Specification for inclusion in that document.

All the remaining CSDR action items were assigned to the appropriate group for resolution and all items were closed within the required schedule.

The next review of the electrical system was conducted in a series of meetings beginning in November 1971 and continuing into May 1972. The Systems/Operations Compatibility Assessment Review (SOCAR) objective was to review the mainstream program activities for compatibility and develop a good understanding between hardware design and planned hardware operation by directly interfacing the responsible Skylab systems design/development personnel and the operations personnel.

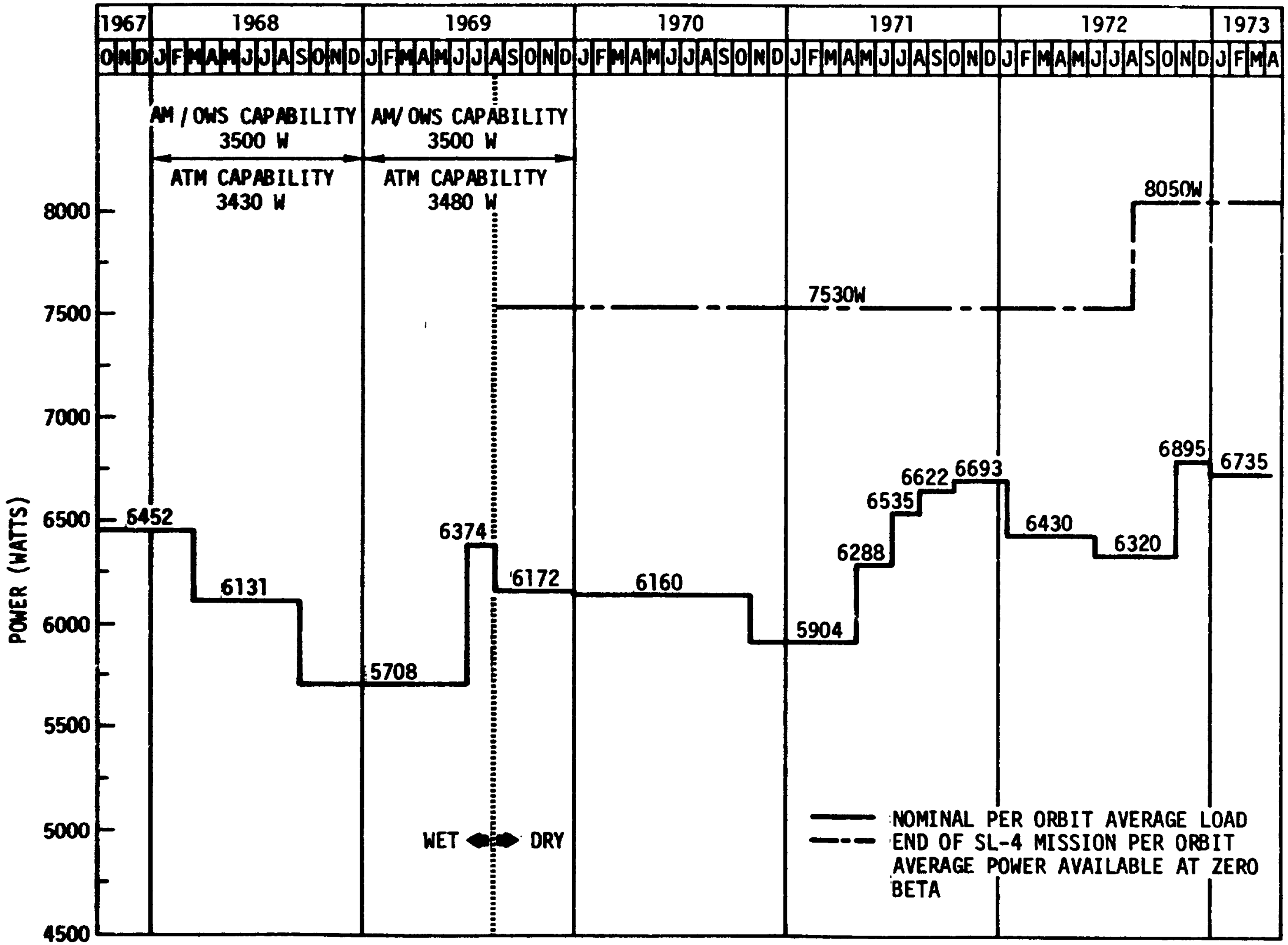


Figure 1.1 Predicted Orbital Load History

The SOCAR was a thorough review of the electrical systems design, systems tests, and operational documentation. All participants were directed to review the applicable areas to be discussed at each of the SOCAR meetings and to report changes or comments as required.

Numerous special study results were presented during the SOCAR meetings to insure that the hardware design met all design requirements. Review of the hardware design included reports evaluating corona, lightning, static electricity and shock, sneak circuits and circuit protection. Each of these subjects were reviewed in detail by the SOCAR team members. Action items were assigned if further investigation was required and the required clarification or explanation was given at a subsequent meeting. In addition to these special studies the results of the systems testing were reviewed. Special attention was given to the test anomalies and the disposition of the anomalies. Since many of the system tests had not been completed at this time the test requirements documents were reviewed by the SOCAR team to determine if the test requirements were accurately and adequately described. Further evaluation of system testing was included in the next review phase.

The SOCAR team also reviewed each of the 42 single failure points (SFPs) in the electrical system. Each SFP was analyzed in detail and dispositioned by the SOCAR team. Three SFPs were eliminated by redesign; 12 were acceptable because a work-around was available to correct a failed condition. Twenty-one SFPs were considered to be acceptable risks because of a high level of confidence from previous performance or minimal degradation affect of the failure. The remaining six SPFs reviewed by the electrical SOCAR team were referred to other groups for disposition.

To complete the review of the power system design, all waivers and deviations to the CRS requirements were reviewed and dispositioned. Additionally the system operational constraints and limitations were reviewed and revised as required to properly reflect the planned system operation.

The SOCAR team was also responsible for reviewing the operational documentation to insure that the planned operation was compatible with the hardware design. The documents were reviewed with the document custodian for accuracy, and comments were submitted where required. The operational documents were in a preliminary state at this time and many comments were submitted to the custodians for incorporation.

The operational documents reviewed included the Skylab Operations Handbooks, both; Volume I, which included the systems description, and Volume II, which contained the system operating procedures. These handbooks were prepared separately for the two Skylab electrical power systems; one set covered the ATM system, and another set covered the AM/OWS system. In addition, Volume IV of the Operational Data Book, which contained the performance data, was reviewed by the SOCAR team.

One of the most important operational documents reviewed during the SOCAR meetings was the Flight Mission Rules. This document contained a group of rules to be used during the mission to minimize the need for real time decisions. Emphasis was placed on identifying all probable causes of redline violations. The mission rule reviews were conducted in SOCAR team leaders meetings. The JSC SOCAR team leader was the document custodian for the EPS sections. All known mission constraints were identified and included in the document.

The data presented during the SOCAR confirmed that the existing electrical power system design was adequate to meet or exceed the design requirements. Additionally, it was concluded that with continuing hardware designer review the operational documentation would make a timely transition to its final flight support configuration.

To accomplish the objectives of SOCAR, 19 meetings were scheduled to assure that all design and operational data was reviewed. Only five action items were not resolved and/or closed during the SOCAR time frame. The five open items required additional data or action to be taken properly document system performance or operational procedures. None of them impacted the hardware design or its certification for flight. All items were resolved and closed prior to the DCR.

The review of the Skylab electrical power system continued through July 1972 with the Design Certification Review (DCR). The purpose of the DCR was to review the design and performance requirements at the system level as specified in the CRS, module CEI Specifications, module ICDs, and as clarified in the minutes of the Intercenter Electrical Panel, and to verify by test and analysis that the design requirements were satisfied.

All design and performance requirements were listed, and the type of verification was identified, either by analysis or tests. Test verification was further divided into breadboard, component, module, or system tests. The results and conclusions of the verification of each requirement were included with plans for future test that impose verification. The DCR confirmed that all electrical power system requirements had been verified by test or analysis.

During component and module level testing, several test problems resulted in minor redesign or piece part replacement. During the DCR each of these problems was analyzed in detail with the corrective action to increase confidence in the ability of the system to meet the performance requirements. Each problem was listed individually, and its significance to the system operation was given. The corrective action was then shown for completion of the analysis. Some additional test anomalies were being analyzed during the DCR time period but it was not expected that the resolution of any of these would have a major impact on the electrical power system design.

Additional DCR effort included a re-review of the SOCAR material. All SOCAR tasks were updated, where applicable, to insure that the electrical power system could be certified as flight ready.

The DCR concluded that the electrical power system, as built, was capable of supporting the imposed Skylab mission operations, however, its ability to meet required performance requirements since the module CDRs had been reduced due to additional loads and Z-LV-E requirements. Potential Z-LV-E operational requirements being considered caused additional concern regarding the capability of the system to meet those power requirements.

A Skylab Cluster basic design requirement was for protection of all operational systems against damage from lightning strike. Imposed was a structural assembly that provided a continuous, circumferential, electrical path from the forward tip of the payload shroud to the aft interface of the OWS, including all points along the length of the stowed cluster. The cluster consisted of 4 major structural assemblies that formed the outer conductive shell: 1) payload shroud, 2) airlock shroud, 3) instrument unit, and 4) orbital workshop.

The first three being of a regular structural profile, provided the imposed electrically conductive path by use of standard ground strapping and mating surface electrical bonding techniques.

The OWS was not a regular structural profile as it included several protuberances such as; the solar array beam fairings, several tunnels, for wiring protection, and piping routed along the external tank structure. A deployable meteoroid shield covered the entire OWS tank wall area, complicating the method used to assure that an electrically continuous path existed as it did on the prime structure for lightning protection purposes.

Non-deployable structures of the OWS were bonded in the same manner as other cluster elements. On the deployable structures, the spring clip method, developed and flight proven from the SIVB program were used. This method made forced mechanical and electrical contact with a piece of electrically bonded structure. Discharge paths were provided over the deployable perimeter of the assembly (e.g., SAS Fairing) at no greater than 5 foot intervals. This method was implemented, on the forward and aft ends of the meteoroid shield, and on both SAS beam fairings and the main tunnel, of the OWS.

d. Skylab Caution and Warning System. The Saturn Workshop (SWS) Caution and Warning (C&W) System provided the crew with visual displays and audible tones when specified cluster parameters reached out-of-tolerance conditions.

The original C&W System design concept consisted of a Call and Warning Unit and an alarm tone generator that was part of the Gemini Voice Control Center. Initially, only twelve parameters were to be monitored. System sensors and associated electronics were non-redundant. Later, the system was modified to consist of an Emergency and Warning Unit capable of monitoring 35 parameters, including fire and rapid loss of vehicle pressure. Redundant sensors and electronics were added along with two klaxons for providing emergency tones. Finally, the C&W System was expanded to contain redundant subsystems within a caution and warning unit. Seventy-six selected parameters were monitored and four separate audio tones, along with visual indicators, were provided.

The total effort regarding this system included the following:

The design and development of the C&W system.

Performance of the integration effort required for defining and evaluating the AM, ATM, MDA, and OWS C&W System for compliance with cluster requirements.

Qualification of system components and verification of system performance.

Performance of C&W System support activities for all Skylab missions.

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2. System Design and Performance Analysis. The electrical power system design evolution resulted in the development of analytical tools that could be rapidly revised to reflect proposed power system design configurations. Due to the complex nature of the power system and the interaction between the power system and other cluster subsystems, the tools developed for design and performance analysis were computer programs. Through interaction of these computer programs the adequacy of the power system design was continually assessed, and the acceptability of the operational procedures were verified.

a. Analytical Tools. Due to the complexity of the Skylab EPS, unique analytical tools had to be developed which had been unnecessary on simpler systems. These tools included sophisticated computer simulations, generation of specialized documentation intended to facilitate analysis, and detailed manual and computer procedures for telemetry reduction and analysis during flight. The analyses for the Skylab Program were divided into two major groups: Premission and Flight.

(1) Premission Tools. The premission analyses made use of four major tools:

Simplified Power Flow Equations,

Skylab Electric Power System Analysis (SEPSA) Computer Program,

Load Assumptions and Power Allocation Documents,

Functional Schematics.

A brief description of these tools is given below.

(2) Simplified Power Flow Equations. The simplified equations given below were used during the early portion of the Skylab Program to provide approximate, quick look, answers to design problems. After the more complex computer programs were developed, these equations took on secondary importance.

(3) Model Description. Using the energy balance concept and the simplified EPS models given in Figure 2.1, the following energy balance, margin determination, and battery DOD equations were developed:

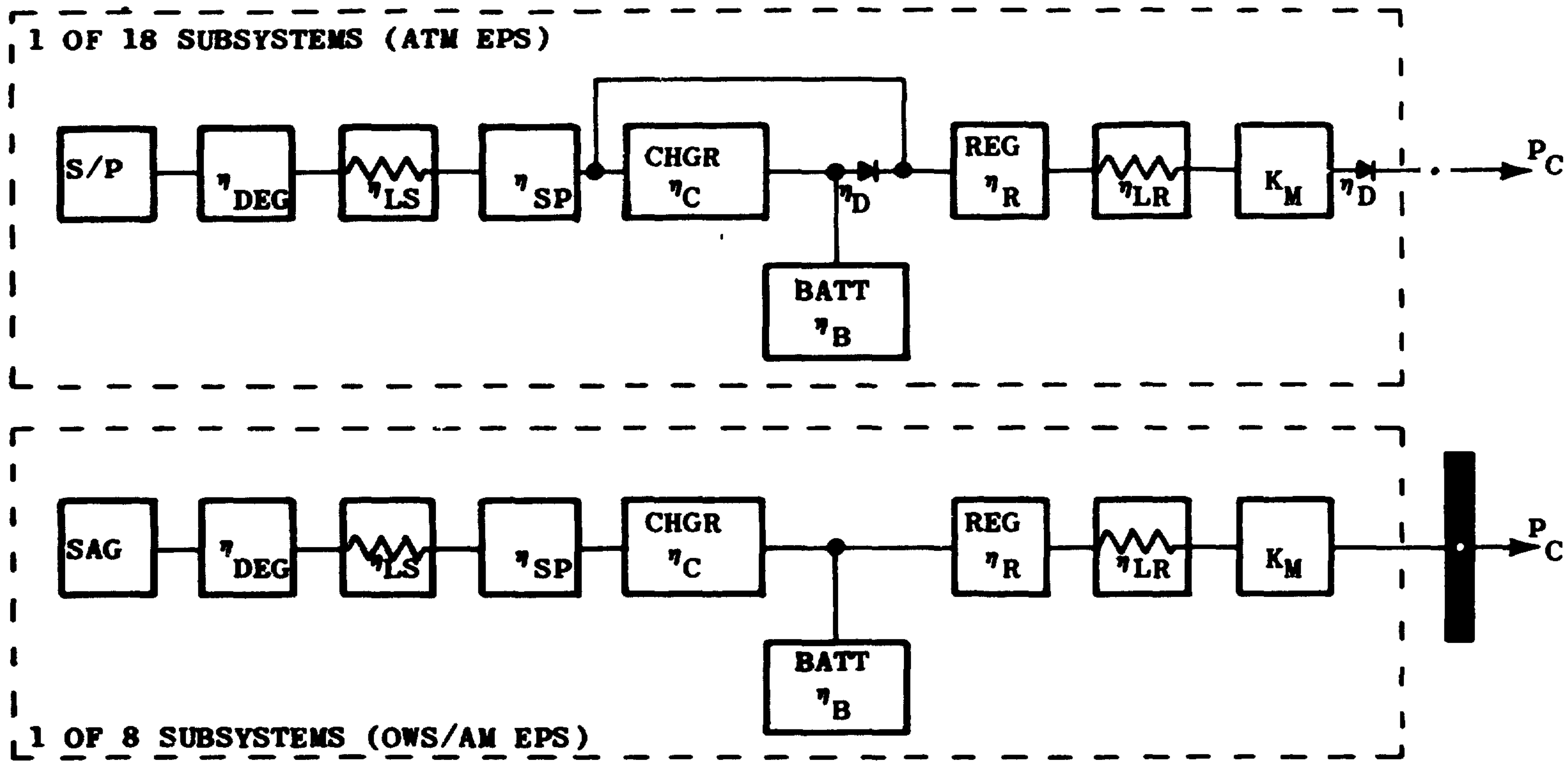


Figure 2.1 Simplified Flow Diagram for Derivation of the Energy Balance Equations.

ATM EPS: $$P_L = \frac{P_{SP}\,\eta_{LS}\,\eta_{DEG}\,\eta_{SP}\,\eta_{C}\,\eta_{R}\,\eta_{LR}\,\eta_{D}^2\,\eta_{B}\,T_C\,N}{T_D + \eta_C\,\eta_{SP}\,\eta_D\,\eta_B\,T_C}$$

$$P_N = P_L - P_E$$

$$DOD = \frac{P_E\,T_D(100)}{N\,\eta_R\,\eta_{LR}\,\eta_D^2\,WH}$$

OWS/AM EPS: $$P_L = \frac{P_{SP}\,\eta_{LS}\,\eta_{DEG}\,\eta_{C}\,\eta_{B}\,\eta_{R}\,\eta_{LR}\,\eta_{SP}\,T_C\,N}{T_D + \eta_B\,T_C}$$

$$P_N = P_L - P_E$$

$$DOD = \frac{P_E\,T_D\,(100)}{N\,\eta_R\,\eta_{LR}\,WH}$$

where: P_L = Energy Balance Bus Power Output Capability,

P_{SP} = Average S/P Output during Illuminated Period of the Orbit,

η_{LS} = S/P to Charger Line Efficiency,

η_{DEG} = S/P Degradation Efficiency,

η_{SP} = S/P Utilization Efficiency,(includes η_D considerations)

η_C = Charger Efficiency,

η_R = Regulator Efficiency,

η_{LR} = Load Regulator to Bus Efficiency,

η_D = Diode Efficiency,

η_B = Battery Efficiency,

N = Number of Operating Subsystems,

T_D = Sunlight Duration,

T_C = Shadow Duration,

P_N = Power Margin,

P_E = Equipment Load,

WH = Rated Watt-Hour Capacity

Km & Km' = Mismatch Factor

(4) Skylab Electric Power System Analysis (SEPSA). This computer program is described in Appendix 4 of this document.

(5) Load Assumptions and Power Allocation Documents. Due to the large number of components and the differing operational characteristics of each, it became apparent that special documentation was required to describe each component. Contractual documentation such as procurement drawings, end item specifications, ICD's, etc., did not have the information necessary to model each of the components. The contractual documents, in general, contained only the maximum power value for design purposes and did not contain the planned operational sequence.

To provide the information required for the EPS analysis, a series of documents were prepared. These included a Power Allocation Document for each module and a Load Assumptions Document for the Skylab. When refinement of the analytical model began to take place, it was obvious that additional data on each component was required to accurately predict the component operational load. The missing data was the distribution system resistances. Both the interconnecting resistances between the major buses and the wiring from the bus to the component and return was necessary for accurate predictions. Since these resistances were not included in either the Power Allocation or Load Assumptions Documents, they were documented in each Load Profile Document release. The Power Allocation and Load Profile Documents, together, contained the following data:

(a) Power required for each operational mode at the required range of input voltages. For resistive loads, the difference in the electrical load between 24 volts input voltage and 30 volts is very significant. For some devices, such as inverters, a constant power is required over the range of input voltages. Therefore, it was very important that this characteristic be understood for each component. Peak loads were also identified.

(b) The bus (or source) from which each component received power was identified.

(c) The resistance of the distribution system wiring from the bus (or source) to each component was defined.

(d) The resistance of the interconnecting wiring between the distribution system buses and the power source was defined.

The Load Assumptions Document was essential for definition of the operational sequence of each electrical component. In a large, manned spacecraft, the numerous components were sequenced independently to satisfy a number of operational constraints. The sequencing of some components was by thermostatic controls; some were sequenced over ground stations; some to support experiment operation or astronaut tasks; while other components had operated continually to maintain spacecraft control and monitoring. It was therefore, essential that the operational sequences of each component be identified early in the development of the analytical model to facilitate accurate prediction of the electrical power requirements. The Load Assumptions Document contained the following data:

(a) The duration of the operation of each component at each operational power level.

(b) The factors affecting the operational sequence such as temperature, ground track, etc.

(c) The relationship of the operational sequence to that of other components.

The use of these documents provided the required visibility for design verification, premission planning and mission support by each contractor and discipline area.

(6) Functional Schematics (Electrical). To accurately model and analyze the electrical system, it was essential that the configuration of the system be clearly understood. To achieve a clear understanding of the configuration required that all drawings be reviewed. In most spacecraft this requires reviewing both design and fabrication drawings of the prime contractor and numerous subcontractors and vendors. As design changes were implemented, the drawings were continually reviewed to assure that the analytical model was accurate to the current design. In addition, it was sometimes very difficult to clearly model the relationship of the components by reviewing schematics intended for manufacturing usage (such as wiring schematics or packaging drawings).

To eliminate the problems discussed above and to ensure that the proper configuration was used by all groups for design analysis and operational predictions, an accurate set of functional schematics was essential. This type of drawing facilitated the understanding of the operation of a complex component of the power system. The execution of commands was easily traced and the interaction of one component with another was more easily visualized than through block diagrams or wiring diagrams.

The functional schematic presented all circuitry to a level of detail sufficient to explain the interaction between all major components in the EPS. The component nomenclature, reference designators and bus identification was consistent with that used in other program documentation. Individual piece parts were shown when required for clarity (such as, blocking diodes). Additionally, all EPS controls, monitoring, and switching capability were depicted. These included relays, motor driven switches, toggle switches and circuit breakers.

(7) Flight Tools. The analytical tools used during the mission were identical to those used premission except for the following:

Electrical Power System Telemetry Evaluation (EPSTE) Computer Program,

EPS Engineering Data Package.

(a) EPSTE. This computer program was developed for analysis of telemetry data supplied on magnetic tape by MSFC. Its main purpose was to supply updated parameters for use by the SEPSA computer program. Such parameters included charger and regulator efficiencies, battery voltage and current profiles, etc. The program was used as an adjunct to manual data analysis in providing the necessary update of premission electrical parameters.

(b) EPS Engineering Data Package (40M35744). The EPS Engineering Data Package was intended to form a general data base for use in analysis of the Skylab Electric Power System during mission support activities. The data provided was parametric and time varying in nature and considered both the normal operating mode and several contingency cases. The parametric data was divided into six major categories: Attitude-trajectory data, Solar Array Data, Battery data, Cluster Power Distribution System Information, Bus Power Capability Analyses and Statistical Loads Analysis.

These data were intended to be used for quick look analyses and were updated and reissued prior to each manned mission.

b. Contingency Studies. Prior to the SL-1 mission, several studies were performed to analyze system or component malfunctions which would drastically effect the planned mission but which would not necessarily abort the mission. These malfunctions were termed contingency operating modes. The major specific studies were:

Inability to deploy the OWS Solar Array,

Loss of AM Telemetry System,

Inability to deploy the Meteoroid Shield,

Failure to deploy the ATM,

Inability to deploy the ATM Solar Arrays.

A short summary of the results of these analyses follows:

(1) Inability to Deploy the OWS Solar Array.*

(a) Failure. OWS solar wing section(s) fail to decinch and/or deploy.

(b) Program Impact.

Adequate electrical power is available to support manned activation and a limited mission. Power management plan required.

Degraded OWS thermal control and meteoroid protection if meteoroid shield cannot be deployed. Both OWS ~~SAS beam fairings must~~ be deployed to allow shield deployment.

Manual decinching and deployment of the OWS solar arrays is not feasible.

(c) Resolution.

Limited mission can be performed based on the degraded power capability. Power management plan required.

(d) Procedures.

No crew action is possible to deploy solar wings.

* NOTE: OWS Wing 2 was torn off following loss of the meteoroid shield during early boost. Wing 1 was constrained in a partially deployed configuration by remnants of the meteoroid shield for the first 25 days of the mission. This contingency analysis proved invaluable during the early mission days and with wing 1 deployed, a segment of the analysis became standard operating procedure for the remainder of the mission.

(2) Loss of AM Telemetry System.

(a) Failure. Loss of AM telemetry system; no real or delayed time data.

(b) Program Impact. Loss of knowledge of airborne system status except for onboard readouts.

(c) Resolution. Crew to monitor systems and relay available data to ground via real-time voice and television; tape recorders and film on earth return.

(d) Procedure.

No repair capability. No crew procedures possible.

Contingency action to be taken real-time.

(3) Inability to Deploy the Meteoroid Shield.

(a) Failure. Meteoroid shield fails to deploy.

(b) Program Impact.

Risk of meteoroid penetration is acceptable.

OWS gas temperature will not remain within crew comfort box at 0^{o} and 60.5^{o} beta angles for -3 sigma conditions.

Experiments utilizing scientific airlocks will be lost.

(c) Resolution. To maintain OWS within crew comfort box, divert power to OWS heaters by off-loading other system loads.

(d) Procedures.

No crew procedures are required.

Contingency action to be taken real-time.

(4) Failure to Deploy the ATM.

(a) Failure. ATM locked in launch position.

(b) Program Impact.

APCS software change required.

Adequate electrical power is available for docking and possible manual deployment.

Manual release and rotation of ATM is functionally possible (involves crew hazard; crew training).

(c) Resolution.

APCS software changes to maintain attitude control.

Possible attitude reorientation; power management.

CSM dock to MDA radial port; attempt manual ATM release and rotation.

(d) Procedure.

Requires special tools to be taken up on CSM.

There are feasible methods for manual releasing and rotating the ATM to the deployed position.

(5) Inability to Deploy the ATM Solar Arrays.

(a) Failure. ATM solar wing(s) fail to decinch and/or deploy.

(b) Program Impact.

Adequate power is available to permit initial crew activation and manual solar wing deployment. Power management plan required.

Degradation of ATM command and telemetry capability.

Manual decinching and deployment of one or more solar wings is required. Provision is being made to obtain special tools required to decinch wing.

Near normal experiment objectives can be achieved during the first 14 days with the following limitations:

Attitude control is by 2-CMG control only. Deactivated rate gyros are activated for ATM fine pointing only.

The vehicle cannot achieve Z-LV. Therefore, Z-LV EREP is not possible, i.e., SI EREP only. All biomedical, ATM and Corollary experiments can be accomplished.

After the CSM fuel cells have been depleted, no mission is possible unless critical systems are severely degraded or offloading is available from the CSM. (May 14, 1973 Launch Date.)

An extended mission beyond 14 days with no CSM offloading is possible if the launch date of SL-2 is delayed 20 days (from May 14, 1973) to provide maximum solar array power during the second half of the mission.

(c) Resolution.

Manually deploy solar wing(s) via EVA.

If deployment cannot be accomplished, a power management plan will be required.

(d) Procedure. Method for manually decinching and deploying ATM solar wing has been developed.

c. Flight Readiness Reviews. A series of module Flight Readiness Reviews (FRRs) were held after the DCR review was complete. These module FRRs assessed that readiness of each module to support the total Skylab mission. Both the AM and the ATM electrical power systems were determined to be ready to support the mission. There were no open items against either the AM or ATM power systems.

The Cluster FRR was held in April 1973. The Skylab electrical power system presentation revealed that some testing was in process. CBRM life testing, to verify the relocation of the third electrode, was in process and was completed in June 1973. Additional testing was on schedule. The presentation showed that there were no open problems from module FRRs.

The Skylab power system was certified ready to support the Skylab mission and to meet all design and performance requirements.

A status of the Skylab system was presented at the SL-3 FRR, early in July 1973. Degradation of the system capability from the premission predictions was noted. The major source of the degradation was the loss of one-half of the AM power generation system capability due to the loss of the solar array wing. The major source of degradation in the ATM power system resulted from the loss of one CBRM due to a regulator failure. These configuration changes were noted and revised power system capability predictions for SL-3 were generated for presentation at the FRR, together with the revised electrical load requirements for the mission.

The FRR power system presentations showed a worst case power margin of 500 watts for the solar inertial flight mode. The Z-LV-E flight mode showed a worst case power margin of minus 1200 watts and therefore, power management was required for worst cast Z-LV-E passes. A possible offloading, of 1500 watts was shown in the FRR presentation and therefore a positive power margin of 300 watts was possible for the worst case Z-LV-E passes identified. The Skylab power system was therefore verified ready to support the SL-3 mission.

A similar FRR was held in October 1973 prior to launch of the third and last manned Skylab Mission. The loss of one additional CBRM during the SL-3 mission was noted leaving a total of sixteen active CBRMs. A plan was presented to recover the equivalent of one CBRM during the SL-4 EVA by interconnection of CBRM 3 and CBRM 5. An additional loss of CBRM capability was reported due to low CBRM battery capacity detected during inflight battery capacity tests. Due to this low capacity of a limit of 9 ampere hours DOD was imposed on the CBRMs. The loss of TV Bus 2 due to a short was revealed. The short drew 500 amps for 2.5 seconds but operation was continued from TV Bus 1.

The FRR power system presentation showed a worst case power margin of 200 watts in the solar inertial mode. The maximum battery DOD during a 120 degree Z-LV-E pass centered at noon with a AM Reg Bus OCV of 29.4 was increased to 54 percent for AM and 22 percent for ATM. With these changes, the Skylab power system would have the ability to support the SL-4 mission and was verified ready to support the mission.

d. Skylab Caution and Warning System. The finalized requirements for the C&W System are defined in the Cluster Requirement Specification, RS003M00003, Appendix H. A summary of these requirements is presented below.

(1) Caution and Warning System Purpose. The C&W System for the cluster (CSM docked to SWS) was required to monitor the performance of itself (voltage only) and other selected systems parameters, and alert the crew to imminent hazards or out-of-limit conditions which could result in jeopardizing the crew, compromising primary mission objectives, or if not responded to in time could result in loss of a system. Parameters monitored by the C&W System were to be categorized as either EMERGENCY, WARNING, or CAUTION. When any of the parameters reached the predetermined out-of-tolerance level appropriate visual and acoustical signals were to be activated.

(2) Caution and Warning Subsystems Each vehicle (SWS or CSM) C&W System was to consist of the following:

(a) Emergency Subsystem. The emergency subsystem was to alert the crew to defined emergency conditions which could result in crew injury or threat to life and required immediate corrective action, including predetermined crew response. The emergency subsystem was to alert the crew by triggering an acoustical alarm system within the vehicle atmosphere and by providing typical warning category outputs. The emergency subsystem was to be DC isolated from the caution and warning subsystem.

(b) Caution and Warning Subsystem. The caution and warning subsystem was to alert the crew to defined caution or warning out-of-tolerance conditions. All outputs of the caution and warning subsystem were to be displayed on the caution and warning system panel(s) and were to generate the appropriate caution or warning tone for routing to the crewman earphones and speaker intercom assemblies (SIA's). The caution or warning conditions were defined as follows:

<u>1</u> Caution. Any out-of-limit condition or malfunction of a cluster system that could result in not meeting primary mission objectives or could result in loss of a cluster system if not responded to in time. Crew action was required although not immediately.

<u>2</u> Warning. Any existing or impending condition or malfunction of a cluster system that would adversely affect crew safety or compromise primary mission objectives. Immediate action by the crew was required.

3. Testing.

a. Pre-Mission. Testing of the Skylab EPS was conducted at the component, black box, system, subsystem, and flight vehicle levels. The objective of the test program was to assure that the flight vehicle EPS could meet all the Skylab requirements with a high level of confidence. The testing was divided into three categories; qualification, development and confidence, and flight vehicle. The chronology of these tests is summarized on the history chart of Figure 3.1. Details of each test are given in other program test reports. Qualification testing was performed on all individual components and functional units which were to comprise the Skylab EPS. Qualification testing on representative EPS hardware is illustrated in Table 3.I.

Qualification testing was performed on all components comprising the ATM Electrical Power System, Table 3.II. In some cases, an assembly was qualified by similarity to another assembly. As an example, the measuring distributors were all basically the same item; therefore, the complete series of tests was conducted on only one distributor and the remainder were qualified by similarity.

Due to the mission essential nature of the solar cell modules, CBRMs, and PCGs, life tests were run to determine their probable characteristics of performance over the lifetime of the mission. As built solar cell module thermal cycling life testing of approximately 4000 cycles was performed at MSFC.

The ATM solar array utilized designs by two separate contractors, so modules from each were tested. During life testing of the solar cell modules, the output power degraded more than predicted.

Six CBRMs were submitted to an eight-month simulated mission in a thermal vacuum environment. All parameters were controlled to within the mission predicted range. During the storage mode, after the simulated one-half mission, two battery failures occurred. The failures were traced to shorted cells that evidently resulted from non-uniform pressure on the cell plates in the third electrode area. The cell design was modified to relocate the third electrode. The test was completed with new cells without the third electrode relocation incorporated. Subsequent life testing with flight configured cells in the battery completed over 4000 cycles, at launch, without cell failures.

Significant development and confidence testing, Table 3.III, was necessary prior to committing the hardware to system level testing and finally to assure flight readiness. The final EPS testing was on the flight vehicle. This primarily verified the compatibility of the EPS with all other systems, and verified the flight worthiness of the actual flight system. ATM tests verified design feasibility. Many ATM network components were Saturn qualified parts and thus imposed testing was minimal. The progression of the AM EPS through the

Space System Testing (SST) is shown by Figure 3.2. These are the major tests, changes, and retests which verified that the AM EPS design met all requirements and that the EPS hardware was ready for flight. The procedures for the SST and the test results are detailed in the various Service Engineering Data Reports (SEDRs) referenced.

Simulated flight tests, SEDR D3-E75-1, Volume II, demonstrated both the operational and the electromagnetic compatibility between the AM/MDA supporting systems and the earth resources experiment package (EREP).

Table 3-IV summarizes the significant EPS problems, which occurred during SST. This table also summarizes the solution/action which was taken to overcome each problem, and it references the appropriate associated documentation.

The ATM module (systems) tests were conducted on the integrated ATM module. Included in the systems qualification and acceptance testing of the ATM were specific procedures to determine the compliance of the Electrical Power System with the design and interface requirements.

Bus resistance and single point ground checks were run to verify that: the positive buses were isolated with and without the ESE and C&D Panel connected the common bus potential was above the vehicle skin prior to connection of the ESE and C&D Panel and was electrically connected to the vehicle skin when the ESE was connected.

Power distribution and control tests were conducted to verify the control of power by the C&D Panel, switch selector, and ESE, including the verification of redundant control lines; the distribution of DC power by monitoring for correct voltage and polarity at the black box before being connected; and the distribution of AC power by monitoring for correct voltage and phase rotation at the black box interface without the black box being connected.

The control and display circuits associated with the Electrical Power System, CBRM control, and regulation, were exercised to verify the commands to and response from the CBRMs, the C&D Panel, and ESE; the TM signals from the CBRMs; the CBRM power sharing capabilities; and to verify operations during simulated orbit cycles of 58 minutes of day and 36 minutes of night.

Full ATM power up/down was accomplished to verify that the ESE was ready to support testing; to power up the ATM to a level where the

EPS and TM systems were ready to support testing; and to power down the ATM and ESE.

A networks system checkout was conducted to verify the functions of the EBW firing units and associated circuitry; the operation of the EVA lighting systems; the operation of the subsystem blanket heaters: the switch selector inhibit circuitry; and the watt-hour assembly operation. Telemetry signals associated with the ATM EPS were also verified.

The thermal performance of the ATM prototype unit under a simulated space environment was evaluated. The results of the qualification testing on the Electrical Power System were acceptable.

One of the major objectives of the systems qualification was to identify problems in the ATM Prototype Unit that could affect the ATM Flight Unit. Qualification testing provided the opportunity to correct these problems prior to the acceptance testing of the ATM Flight Unit.

Systems acceptance testing of the ATM Flight Unit consisted of the same series of tests as the systems qualification testing of the ATM Prototype Unit. The systems acceptance tests were designed to verify that the ATM Flight Unit met the full mission specification requirements for the ATM program.

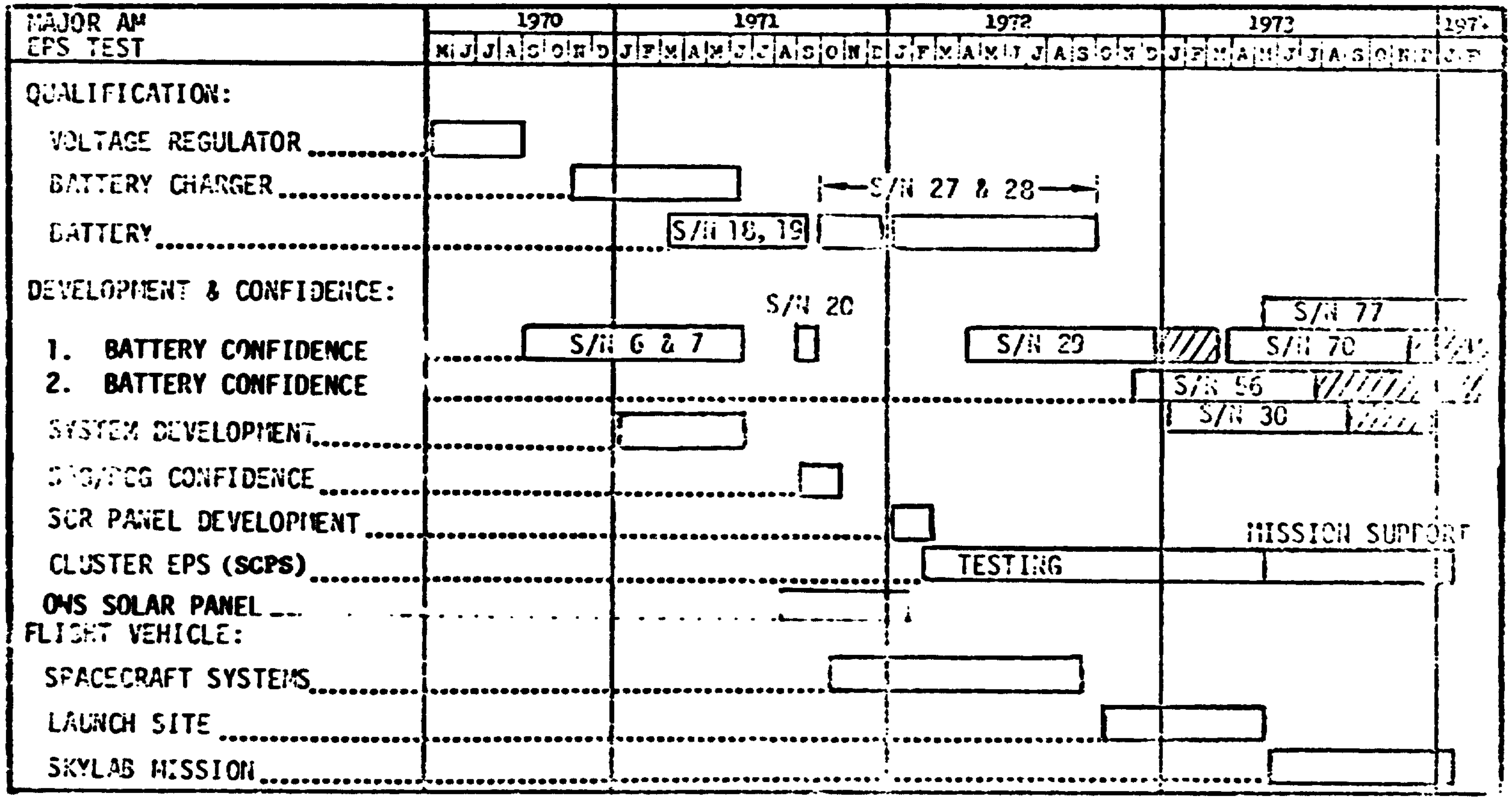
Sunlight tests were performed on solar cell modules and solar array panels to calibrate the as-built performance. No significant problems were encountered in these tests.

Solar cell temperature coefficient tests were performed to determine the temperature coefficients over the expected mission temperature range. No significant problems were encountered during this test series.

A recap of the most significant problems identified in the subsystem tests are shown in Table 3-V.

Further testing at the launch sites verified the status of both systems through launch. Figure 3.3 summarizes the ATM test flow at the launch site.

b. Mission (ground). During the mission conditions occurred which required ground testing with the SCPS to verify analytical results. These are summarized in Table 3-VI.



– CONFIDENCE TESTING BEYOND AIRLOCK REQUIREMENTS

Figure 3.1 Major EPS Test History AM and ATM

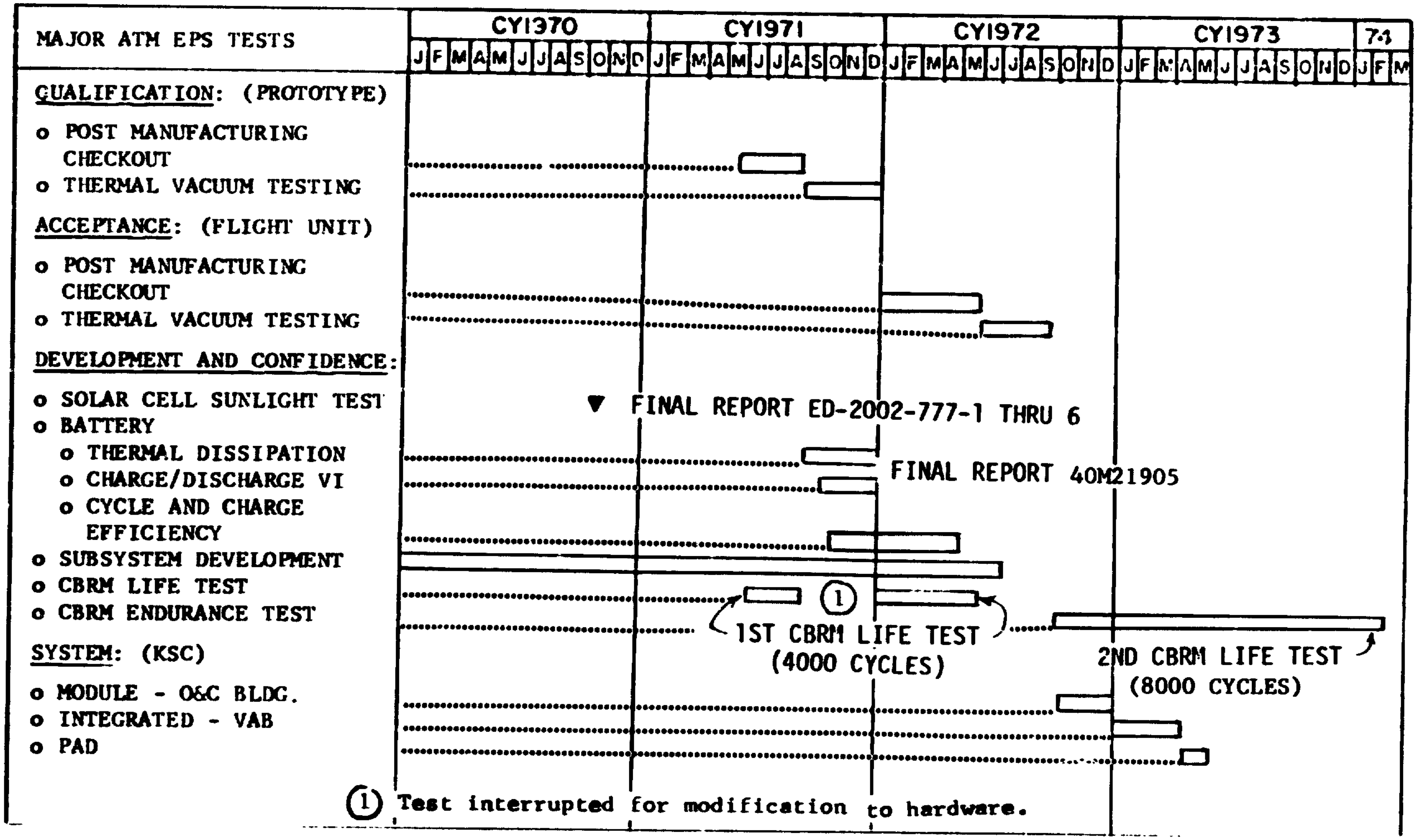


Figure 3.1 (cont.) Major EPS Test History AM and ATM

UNITS TESTED	FORMAL DOCUMENTS	TEST	SIGNIFICANT REMARKS
2	PROCUREMENT SPEC 61B769006 QUAL TEST PROC 714244 QUAL TEST REPORT 2639	QUALIFICATION	Test samples were flight units modified to include internal thermocouples. Due to humidity test failure, a design modification to add a moisture seal was incorporated. Retest was successful. In addition to normal testing one unit passed 1000 hours of life test and additional units accumulated over 15,000 hours of cycling tests on 61B769004-13 for S/N 29, and 61B769-004-19 for S/N 70 batteries during Development and Confidence testing.
ALL	ACCEP. TEST PROC 714243 (ATP)	ACCEPTANCE	Test required a test console consisting of inflight solar array simulator, battery simulator, and flight type voltage regulator. Test verified compatibility of components and confirmed peak power tracker action. A special test connector permitted accuracy of measurements not attainable in flight. Internal redundancy was also verified.
ALL	ACCEP. TEST PROC. 714-243	INSTALLATION ACCEPTANCE	This test was to be repeated if a unit was stored longer than 12 months. It consisted of physical examinations and room temperature performance portions of the ATP and used an identical test console.

Table 3.I Qualification and Acceptance Test Summary
AM Battery Charger

UNITS TESTED	FORMAL DOCUMENTS	TEST	SIGNIFICANT REMARKS
SEE REMARKS	QUAL. TEST PROC 107 QUAL TEST REPORT 107	QUALIFICATION	Special equipment design and assembly was imposed. These included: Battery thermal control, accomplished by special coolant bench plumbed for flight configuration cold plates, radiated heat was precluded by encapsulation in granulated insulation material, charge/discharge controls provided by automatic test console which included; programmed loads, day/night cycle adjustment with beta angle compensation, charge voltage limit and recharge fraction adjustments, battery SOC data, and individual cell voltage monitoring, and a data acquisition system. Burst pressure testing was waived. Two units (SN 18, 19) which included cell plate geometry and case material design modifications completed all except cycle life testing which was stopped based on data from S/N 6 testing which lead to elimination of the plate holddown block. New configuration (S/N 27) completed all tests including 4000 cycle life requirement. S/N 28 failed at 3029 cycles due to workmanship inconsistencies in plate tab shaping. Confidence was maintained by S/N 29 life testing having completed 6 of 8 test months at this time. New batteries (S/N 30, 56) of same configuration and new configuration (S/N 70,77) were placed on life test and had no cell failures at 4000 cycles. The S/N 70,77 battery configuration designated -19 became the flight units.
ALL	ACCEP TEST PROC 180	ACCEPTANCE	Test data was used as engineering information pertinent to performance characteristics. During all cycling and capacity discharging a temperature of $75^oF \pm 5^oF$ was maintained. This test revealed a thermal problem (temperature gradient) which limited long cycle life and resulted in the battery case material design modification.

Table 3.I (cont.) Qualification and Acceptance Test Summary
AM Battery

UNITS TESTED	FORMAL DOCUMENTS	TEST	SIGNIFICANT REMARKS
ALL	ACCEP TEST PROC 180	PRE-INSTALLATION ACCEPTANCE	Due to delivery schedule all tests and inspections were witnessed by MSFC at the vendor facility. KSC verified only visual inspection, wiring integrity, and full state of charge. A full capacity cycle was eliminated as source inspection, special delivery arrangements, and in-vehicle verifications scheduled after installation warranted the time saving change.
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Table 3.I (cont.) Qualification and Acceptance Test Summary
AM Battery

UNITS TESTED	FORMAL DOCUMENTS	TEST	SIGNIFICANT REMARKS
2	PROCUREMENT SPEC B769005 QUAL TEST PROC 714282 QUAL TEST REPORT 2586	QUALIFICATION	Test samples were flight units modified to include internal thermocouples.
ALL	ACCEP TEST PROC 714281	ACCEPTANCE	Test required a test console which simulated the AM EPS with regard to input voltage range, wire resistances, remote sensing, etc. a voltage regulator identical to the flight unit was contained within the console to verify parallel operations.
ALL	ACCEP TEST PROC 714281	PRE-INSTALLATION ACCEPTANCE	This test was to be repeated if a unit was stored longer that 12 months. It consisted of physical examinations and room temperature performance portions of the ATP and used an identical test console.

Table 3.I (cont.) Qualification and Acceptance Test Summary
AM Regulator

UNITS TESTED	FORMAL DOCUMENTS	TEST	SIGNIFICANT REMARKS
ALL	TEST REPORT 40M21800	DARK I-V TEST	Qualification modules randomly selected from production modules were rated for power output respective to their current output at a specified voltage, average maximum power point, and compared to the average maximum power point of a standard solar cell module. Established forward diode characteristics and output power baseline data for degradation comparison with subsequent tests.
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Table 3.I (cont.) Qualification and Acceptance Test Summary
ATM Solar Array Panel

UNITS TESTED	FORMAL DOCUMENTS	TEST	SIGNIFICANT REMARKS
ALL	SEDR D3-E72 AND D3-E76.	AT	One light exceeded the maximum current specified for operating in the "low" mode. The illumination level was determined to be below specification requirements at the ATM C&D panel. The crew evaluation indicated that the lighting was dim but adequate. Prior to altitude chamber testing, all MDA interior lights were replaced with modified lights.
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ACCEPTANCE TEST (AT)

Table 3.I (cont.) Qualification and Acceptance Test Summary
MDA Interior Lighting

COMPONENT	TEST PROC/SPEC	TEST REPORT
SOLAR CELL MODULE 40M26410 40M26411	50M26423	40M26452
CBRM 40M26200	40M26709A	40M26993
MASTER MEASURING SUPPLY 40M26271	40M26269A	40M26268
POWER SUPPLY 40M26580	40M26662B	40M26619
POWER TRANSFER DISTRIBUTOR 40M37380	40M39601 50M02408D	40M39608
MAIN POWER DISTRIBUTOR 40M37381	40M39599 50M02408C	40M39606 40M39629
AUXILIARY POWER DISTRIBUTOR 40M37382	40M39600 50M02408D	40M39607 40M39629
CONTROL DISTRIBUTORS 40M37383 40M37384 40M37387 40M37388 40M37393 40M37394	40M39597 50M02408C	40M39604 40M39629
CONTROL & DISPLAY LOGIC DISTRIBUTOR 40M37390	40M3961[illegible]	------
MEASURING DISTRIBUTORS 40M37385 40M37386 40M37389	40M39598 50M02408C	40M39605 40M39629

Table 3.II Qualification Test Summary for ATM Components

COMPONENT	TEST PROC/SPEC	TEST REPORT
J-BOX ASSEMBLIES 40M33680 40M33681 40M33691	40M39613 50M02408C	40M39615
SWITCH SELECTOR MOD-II 50M67864-7	 50M02408C	40M51488
WATT-HOUR ASSEMBLY 40M37998	40M39620 50M02408D	40M39621 40M39628
EBW FIRING UNIT 40M39515	40M39566 50M02408C	40M51487 40M39056
EVA LIGHTS 40M51269	DELTA QUAL TEST REPORT SEPTEMBER 1971	
TRANSIENT FILTER ASSEMBLY 40M38547-1	40M38570 50M02408D	40M39631
MOTOR TRANSIENT SUPPRESSOR 40M38697	40M38704 50M02408D	------
CABLES	CABLES WERE ASSEMBLED FROM A QUALIFIED PARTS LIST. THE END ITEM RECEIVED CONTINUITY TEST, INSULATION RESISTANCE TEST AND QUALITY INSPECTION.	

Table 3.II Qualification Test Summary for ATM Components.(cont.)

TEST ARTICLE	TEST PERFORMED	TEST OBJECTIVE	SIGNIFICANT REMARKS
BATTERY	1. PROTOTYPE	Develop confidence in Ni-Cd battery life characteristics and in their capability to satisfy mission requirements. Also, to justify design modification effectiveness and to improve installed maintenance procedures.	1. Data developed was used for computer input data resulting in performance analyses. Test was terminated due to inability to establish predictable SOC. Data aided in new definition of operation characteristics.
	2. PARAMETRIC DATA		2. This test was follow-on from 1. and resulted in change in cell potting materials and coolant system based upon discovery of temperature gradient problem. Performance definition from 1. was validated.
	3. MODIFIED ALL VIBRATION SUSCEPTIBILITY		3. Test verified the acceptability of eliminating cell holddown and resulted in -9 battery configuration.
	4. MAINTENANCE PROCEDURE DEVELOPMENT		4. Evaluation of various candidate methods revealed that a weekly boost charge of 2 hours would optimize vehicle prep. activities and minimize coolant loop usage.
	5. PRODUCTION TOOL EVALUATION		5. Evaluation revealed that previous poor workmanship quality was corrected by the new production tool.

Table 3.III Development and Confidence Test Summary
AM

TEST ARTICLE	TEST PERFORMED	TEST OBJECTIVE	SIGNIFICANT REMARKS
BATTERY (cont.)	6. **LIFE TEST**	Develop confidence in Ni-Cd battery life characteristics and in their capability to satisfy mission requirements. Also, to justify design modification effectiveness and to improve installed maintenance procedures.	6. Test was imposed by deficiencies in various generations of battery development determined from the prior tests. Flight battery configuration completed 4000 cycles of test and gave confidence in the capability to survive the missions. Two batteries continued tests in parallel with the mission. S/N 30 completed 5704 cycles and lost 5 cells after 5427 cycles. S/Ns 56, 70, and 77 were still under test on 2/11/74. S/N 56 had 7020 cycles accrued then, but lost one cell at 6251 cycles.
	7. **OPERATING CHARACTERISTICS**		7. Table 3.IIIa outlines differences in the tests performed on various configurations caused by design changes, and new requirements.
BATTERY CHARGER	1. **CIRCUITRY DEVELOPMENT**	Develop a high efficiency, reliable, functionally accurate and high power density charger circuit.	1. Redundant, solid state circuitry in each power module was verified to satisfy all test objectives and imposed requirements.
	2. **POWER TRANSISTOR**	(same)	2. Developed an acceptable alternate source for required power transistors.

Table 3.III (cont.) Development and Confidence Test Summary
AM

S/N	TOP-OF-CELL BATTERY TEMPERATURE	TRICKLE CHARGE CURRENT (AMPS)	CHARGE RETURN FACTOR	MAXIMUM CHARGE CURRENT (AMPS)	AVERAGE DOD MANNED PHASE	AVERAGE DOD UNMANNED PHASE	TOTAL CYCLES PERFORMED (Failed Cells)
6	90°F	1.5	1.220	50	11AH/2140 CYCLES	4AH/996 CYCLES	3136 (5)
7	70°F	1.5	1.150	50			3136 (9)
20	50°F	.75	1.076	50	11AH/448 CYCLES	NONE	448 (0)
29	50°F/3611 CYCLES	.75	1.080	63	10AH/2475 CYCLES	5AH/1536 CYCLES	4932 (0)
	60°F/1321 CYCLES	.75	1.098	63	8.5AH/654 CYCLES	3.5AH/267 CYCLES	
70	47°F	.75	1.076	42	8.5AH/3507 CYCLES	3.5AH/1584 CYCLES	5091 (0)
77	47°F	.75	1.076	42	8.5AH/2437 CYCLES	3.5AH/1584 CYCLES	4021 (0)

Table 3.IIIa AM Battery Test Parameters

TEST ARTICLE	TEST PERFORMED	TEST OBJECTIVE	SIGNIFICANT REMARKS
VOLTAGE REGULATOR	1. POWER TRANSISTOR	Develop a high efficiency, high power density, reliable regulator.	1. The required high speed, high BV_{CEO}, high power, high reliability design was unproven. Specification EM 712989 was satisfied after evaluation of various vendors.
	2. FILTER CAPACITOR		2. The required low series resistance of tantalum wet slug capacitors required test verification prior to use.
	3. THERMAL		3. A thermal model for analysis of both steady state and transients was developed.
	4. HIGH TEMP		4. Demonstrated design adequacy under worst case conditions.
PCG	1. SYSTEM DEVELOPMENT	Verify individual and parallel PCG operation and operations of power distribution system at both ambient and temp/alt conditions.	The results of max load testing are summarized in Tables 3.III.b and 3.III.c and showed that max load capability depends on battery charging characteristics. Failure of a transistor was detected and its effect was minimized by use of a pre-defined work-around which would have been used in flight if required. Contingency operating procedures were verified.

Table 3.III (cont.) Development and Confidence Test Summary
AM

MAXIMUM LOAD CAPABILITY OF INDIVIDUAL PCG'S							
				REGULATED BUS LOAD IN WATTS			
COOLANT INLET TEMP	BETA ANGLE	SIMULATED ATTITUDE	PCG #5	PCG #6	PCG #7	PCG #8	PREDICTED
65°F	0°	SI	544	563	540	540	530
65°F	58.5°	SI	890	930	900	903	850
65°F	73.5°	SI	1354	1415	1423	1388	1500
65°F	0°	ZLV	325	375	320	300	300
65°F	73.5°	ZLV	90	95	85	80	40
36°F	0°	SI	538	538	537	530	533

MAXIMUM LOAD CAPABILITY OF 4 PCG'S IN PARALLEL				
COOLANT INLET TEMP	BETA ANGLE	SIMULATED ATTITUDE	MEASURED POWER (WATTS)	PREDICTED POWER (WATTS)
65°F	0°	SI	2150	2120
65°F	0°	ZLV	1300	1200

Tables 3.III.b and 3.III.c Maximum Load Capability of PCGs.

TEST ARTICLE	TEST PERFORMED	TEST OBJECTIVE	SIGNIFICANT REMARKS
INTEGRATED SAG/PCG	1. SOLAR INERTIAL ORBIT 2. Z-LV-E ORBIT 3. BETA ANGLE 4. PEAK POWER TRACKER 5. TRANSIENTS	Verify compatibility between an individual SAG and PCG under various orbital conditions using flight type hardware.	Compatibility was verified in all cases. Peak power tracker accuracy was 96.2%. The charger shared the load with the battery upon demand. Voltage regulation was proper. Induced transients had negligible effect.
SCR PANEL	1. TRANSIENT INDUCED 2. CONFIDENCE	Verify effectiveness of SCR panel design to resolve charger and battery relay switching problems. Determine stress levels. Accumulate worst case operation data.	Due to circuit wiring resistance stress was less than expected. Worst case operation was satisfactory. Protection was verified and confidence was developed based upon over 500 cyclic operations under worst case conditions.
SKYLAB CLUSTER POWER SIMULATOR	SEE "SCPS BREADBOARD TEST REQUIREMENTS" 40M35693	Demonstrates stable parallel operation of AM/ATM EPS, power sharing, SPG concept verification, failure and contingency	Compatibility between power systems, capability to interface with CSM power system and procedures associated with normal and contingency operation were verified.

Table 3.III (cont.) Development and Confidence Test Summary
AM

TEST ARTICLE	TEST PERFORMED	TEST OBJECTIVE	SIGNIFICANT REMARKS
		mode operations, and effects of orbital operation on the system.	
OWS SOLAR PANEL	SEE REPORT SA-13	Demonstrate structural integrity and establish acceptance criteria dark V-I testing.	Demonstrated design feasibility and confidence to proceed with production.
1/3 WING ASSEMBLY	SEE REPORT SA-2	Evaluate wing section deployment capability.	Wiring abrasion was detected and corrected.
SOLAR CELLS AND PANELS	SEE REPORTS ST-7 AND ST-8	Establish temperature coefficients, mismatch losses and SAG/PCG performance baseline in actual sunlight. (See integrated PCG test described earlier.)	Sunlight and simulated sunlight data correlated. This test verified that pulsed zenon simulation methods can be used to certify system interface compatibility.

Table 3.III (cont.) Development and Confidence Test Summary
AM

TEST ARTICLE	TEST PERFORMED	TEST OBJECTIVE	SIGNIFICANT REMARKS
SOLAR CELL MODULE	**SEE REPORT ST-9**	Evaluate cell and module failure mechanisms under dynamic shadowing conditions and extended tempera- ture cycling.	Module design was modified to single string from dual string concept. Determined the effect of 4800 thermal cycles upon cell interconnectors and solder joints.
SOLAR PANEL	**SEE REPORT ST-10**	Determine thermal cycle degradation levels.	Total of 2100 cycles on two panels with no failures provided desired confidence. Data from this test and SA-9 provided degradation rate predictions as 4.3% max from thermal cycling.
SOLAR CELLS	**SEE REPORT ST-29**	Determine cause and effect of sol der dewetting and low joint strength in solar cells. Study effects of mat'l variables, type of solder, and solder schedule upon wettability and joint strength.	Normal cells have adequate contact strength, but in rare cases, the cohesive strength of the Ti layer is deficient. Contact reliability could be improved by process changes, particularly in the deposition phase. Very little correlation between radiographic appearance and contact integrity. Predicted not more than 0.55% SAS power loss from P-Contact solder joint failure.
SOLAR MODULE	DARK V-I CHARAC- TERISTICS	Establish individ- ual module V-I dark characteristic	Developed a capability to verify solar module performance at anytime without costly, time consuming, array deployment and illumination.

Table 3.III (cont.) Development and Confidence Test Summary

OWS

TEST ARTICLE	TEST PERFORMED	TEST OBJECTIVE	SIGNIFICANT REMARKS
POWER TRANSFER DISTRIBUTOR	Manufacturing Checkout	Verify workmanship and producibility.	Problems encountered due to physical space limitations. Electromechanical redesign required.
CABLES	Manufacturing Checkout	Verify workmanship and producibility.	Problem encountered with flaking of the insulation of the cables during manufacture. A new wire with different type of insulation used.
CBRM	Reg Performance Charger Performance RFI S/A Compatibility	Performance verified up to 450 W from -50°C to 85°C for the regulator.	Added filtering as result of RFI test. Oscillations in S/A compatibility test corrected with a circuit design change.
CBRM	System Simulation Test	Verify proper load sharing by paralleling 2 CBRMs.	Tantalum wet slug capacitors shorted. Caused by reverse biasing of capacitors. Retrofit on all flight units.
CBRM	CBRM test proc 40M26998 test report 40M26994	Life test demonstrated the capability of the CBRMs to survive the ATM mission.	The test also identified a problem in the battery cell that was corrected in a cell redesign. The measured and estimated capacities of the batteries are shown in Figure 7.53. Two factors are significant: one is the slope of the measured capacity and the other is the sharp decrease in the measured capacity at cycle 3800. These appear similar to the measured decrease, which occurred in the flight batteries.

Table 3.III (cont.) Development and Confidence Test Summary
ATM

TEST ARTICLE	TEST PERFORMED	TEST OBJECTIVE	SIGNIFICANT REMARKS
SOLAR CELL MODULE	Solar Cell Module 40M26410, 40M26411 test proc 40M26425	Life test demonstrated the capability of solar cell modules to survive the ATM mission.	Assessment of output power degradation was higher than predicted based upon a re-estimate of mismatching, shelf-life, cable losses, and inclusion of life test results.
FLAT CONDUCTOR POWER CABLES	Thermal Vacuum	Assure Temperature rating would not be exceeded under operational conditions.	No problems encountered.
SOLAR ARRAY PANELS & CELLS	1. Sunlight tests.	1. Calibrate as-built performance.	Results documented in MMC Document ED-2002-777 entitled "ATM Solar Cell, Module and Panel Test Report," dated 10-30-70.
	2. Solar cell temperature coefficient tests.	2. Determine temperature coefficients over the expected mission temperature range.	
	3. Vibration, acoustical, thermal cycling.	3 Design Evaluation.	
	4. Interconnector and insulation, reliability, solar cell matching criteria, reverse bias operation	4. Establish technology and critical criteria and verify concepts.	

Table 3.III (cont.) Development and Confidence Test Summary
ATM

TEST ARTICLE	TEST PERFORMED	TEST OBJECTIVE	SIGNIFICANT REMARKS
	and power optimization.		
INTERIOR LIGHTING	Functional Verification and Illumination level tests. MDA-OCP-D-6002 "Electrical System Functional"	To verify that MDA interior lighting functions and meets illumination requirements as specified.	Two lights exceeded the maximum current specified for operating in the "low" mode. These were removed and replaced with flight spares. A failure analysis of these two lights and a third light that failed during acceptance tests, resulted in a modification to the light assembly to reduce the current requirement.
AM TRACKING LIGHTS	System Compatability	Operate with other systems and at simulated altitude	Verified functions: o individual flash rate and synchronization. o primary and secondary operations. o automatic switchover. o manual and command operations. o EMC/overall system operations. o Tx timeout functional interfaces.
AM DOCKING LIGHTS	End-to-End operations	Verify prime and redundant operation	Verified the same functions as for TRACKING LIGHTS except no Tx interfaces or automatic switchover.

Table 3.III (cont.) Development and Confidence Test Summary
AM/ ATM/MDA

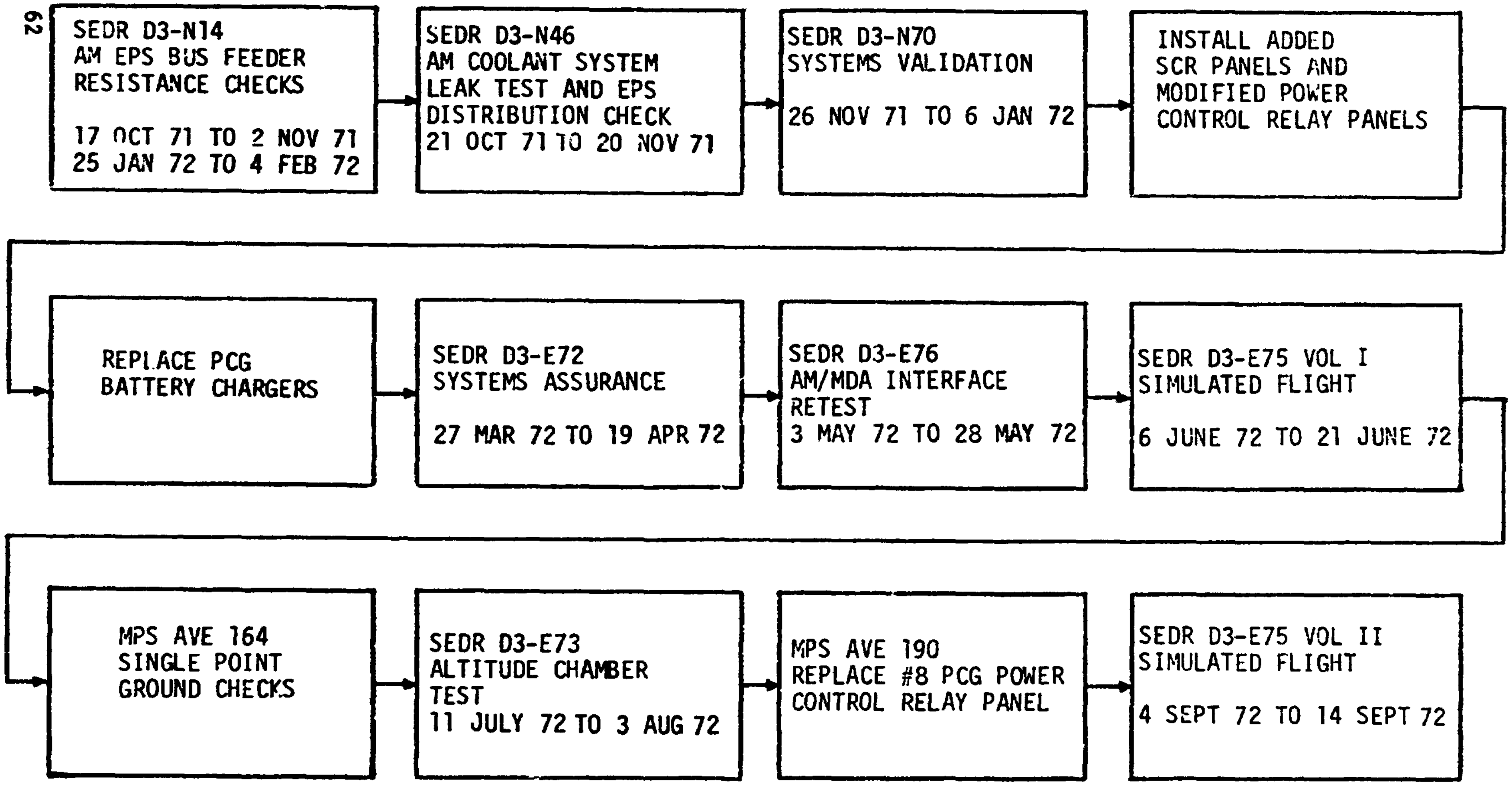

Figure 3.2 AM Spacecraft System Test Flow

ITEM	PROBLEM	SOLUTION/ACTION	REFERENCE
1	No. 6 PCG test battery was found to have a connector with splayed pins.	The battery was replaced and the manufacturer was informed of the problem so that his processes could be corrected.	SEDR D3-N70-1 AR #14 MRR #A111AFG13
2	No. 8 battery charger primary ampere hour meter failed to count down during battery discharge.	Battery charger was replaced and system retested satisfactorily.	SEDR D3-N70-1 AR #176 MRR #A12AFG6
3	After systems validation, all battery chargers were replaced with modified chargers which had different trickle charge current levels and charge return factors.	Systems assurance accomplished the required retest.	ECP 464 SEDR D3-E72-1
4	Battery charger No. 2 lacked wiring to the input voltage monitor points.	Battery charger was replaced and system retested satisfactorily.	SEDR D3-E72-1 AR #10 MRR #A32AFG8
5	Battery charger No. 5 had numerous random and unexplained shutoffs which occurred during peak power tracking while the SAWS was simulating orbital solar array conditions.	Battery charger was replaced and system retested satisfactorily.	SEDR D3-E72-1 AR #38 MRR #A42AFG12
6	Battery charger No. 4 shut off and remained off despite the fact that sufficient array power was available to meet its power demands.	The charger was replaced and system retested satisfactorily.	SEDR D3-E73-1 AR #29 MRR #A72AFG27

Table 3.IV Summary of Significant EPS Problems During SST

ITEM	PROBLEM	SOLUTION/ACTION	REFERENCE
7	No. 5 and No. 6 battery chargers showed a maximum divergence of 9-10% between their primary and secondary amp-hour meter indications.	Analysis of data showed that this divergence was caused by differences in accuracies of the amp-hour meters and by the random error introduced during transition from charge to discharge and discharge to charge. This divergence is a normal occurrence and its random nature will cause it to periodically reoccur.	SEDR D3-E75-1 Vol. I AR #69
8	Voltage regulator No. 7 voltage droop characteristic was out of tolerance.	Regulator was replaced and system retested satisfactorily.	SEDR D3-N70-1 AR #190 MRR #A12AFG7
9	Voltage Regulator No. 5 had blown internal fuses.	Voltage regulator No. 5 and battery charger No. 5 were replaced and system retested satisfactorily.	SEDR D3-E72-1 AR #60 MRR #A42AFG12 #A42AFG11
10	Reg. Adjust Bus 2 pot caused erratic and out of tolerance bus voltages.	Potentiometer stops were damaged. Pot was replaced and system retested satisfactorily.	SEDR D3-N70-1 AR #188 MR #1829
11	Reg Adjust Bus 1 pot was hard to turn and had insufficient adjustment range. Reg adjust bus 2 pot caused erratic and out of tolerance bus voltages.	The problem was found to be binding of the pot shaft against the side of its mounting hole caused by insufficient hole clearance and by the fact that the locking knobs forced the shaft to rotate eccentrically. The design was	SEDR D3-E72-1 AR #49,50 & 95 MRR A42AFG13

Table 3.IV (cont.) Summary of Significant EPS Problems During SST

ITEM	PROBLEM	SOLUTION/ACTION	REFERENCE
11 (Cont'd)		changed to replace the knobs with non-locking knobs and to enlarge the shaft hole clearances. Both pots were replaced and satisfactorily retested in AM/MDA interface retest.	
12	Several failures of PCG battery relays and charger relays occurred.	Problem was traced to high transient currents which welded or otherwise damaged the relay contacts. SCR protection circuits were added across these relays. The relay panels were reworked to replace all relays subjected to the high transient currents and were modified to interface with the SCR protection circuits. Retest was accomplished satisfactorily in SEDR D3-E72-1.	SEDR D3-N70-1 AR #106, 121, 142, 151 MRR #A121AFG4 A121AFG3 A121AFG6
13	CSM B & ATM 2 current sensors were discovered to be interchanged.	The current sensors were changed and the necessary wiring changes were made to return the system to blueprint configuration. Retest was accomplished satisfactorily.	SEDR D3-N46-1 AR #9 NR #421/1672

Table 3.IV (cont.) Summary of Significant EPS Problems During SST

ITEM	PROBLEM	SOLUTION/ACTION	REFERENCE
14	Three shunts were found to be miswired; Battery #2 current, Battery No. 4 current, and array current No. 7	The shunts were rewired per blueprint and retested satisfactorily.	SEDR D3-N70-1 AR #96, 97 & 99 NR #1769, 1771, 1776, and 1770
15	PCG No. 8 discharge limit switch, a momentary toggle switch, failed to return to its center off pos[illegible]on when released.	The switch was replaced and retested satisfactorily.	SEDR D3-E72-1 AR #43 MRR #A42AFG15
16	The OWS Bus 2 Feeder No. 6 circuit breaker was found to have high terminal resistance.	The circuit breaker was replaced and retested satisfactorily.	SEDR D3-N14-1 AR #1 MRR #A101AFG2
17	Panel 214 Utility Power Connector No. 2 was found to be incorrectly clocked.	The connector was returned to blueprint configuration	SEDR D3-E72-1 AR #TPS 19-11 MR #2241

Table 3.IV (cont.) Summary of Significant EPS Problems During SST

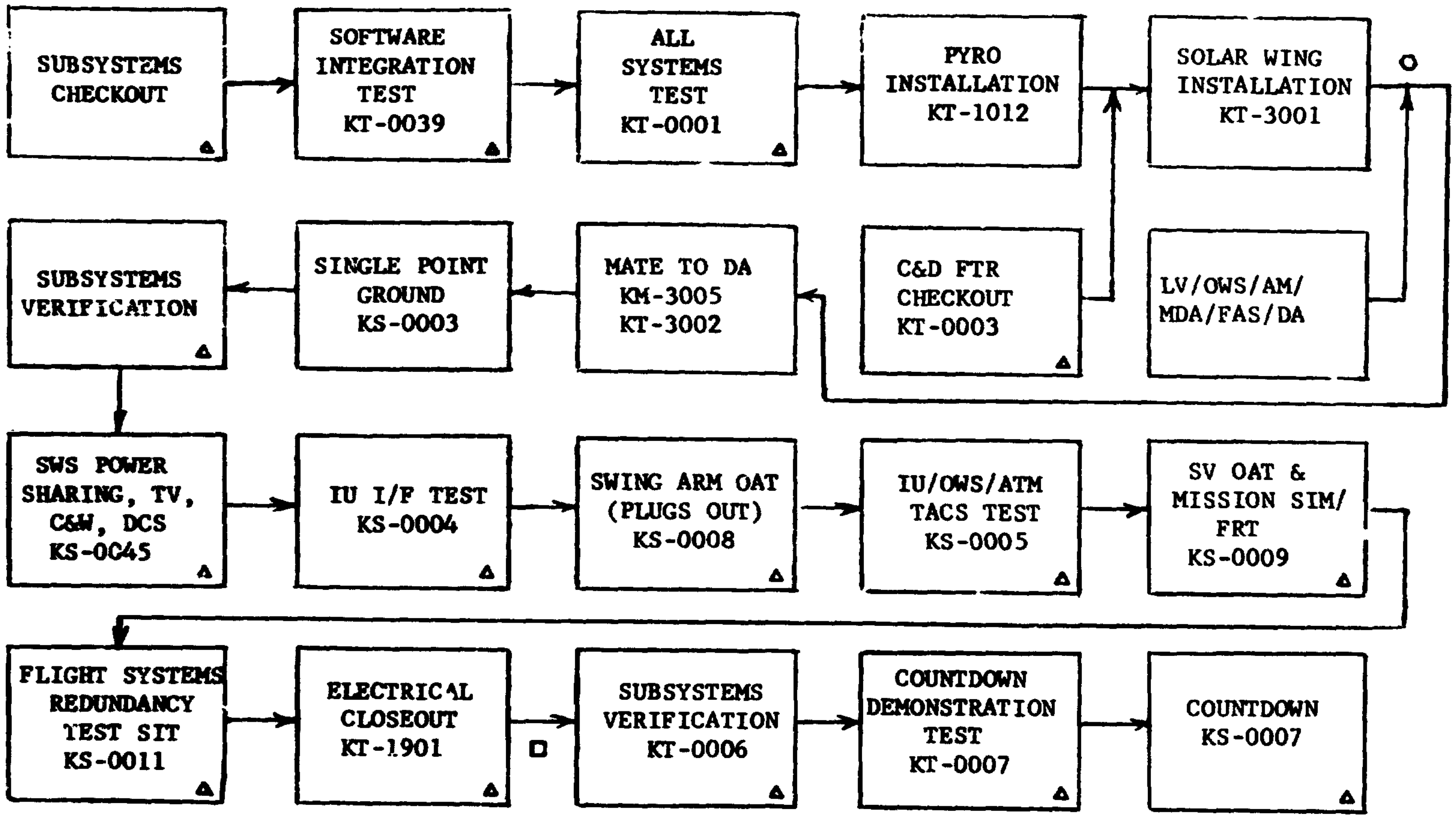

Figure 3.3 ATM KSC Test Flow

UNITS TESTED	FORMAL DOCUMENTS	TEST	SIGNIFICANT REMARKS
PROTO-TYPE	TCRSD 50M02425	PMC	NETWORKS: Bus resistance and single point ground checks resulted in correction of several extraneous grounds. Further checks revealed that, although 7DCOM bus was not directly connected to vehicle skin, the paralleling of resistances resulted in a poor reading. All ATM bus isolation resistances were acceptable both with and without external connections to the ATM. CBRM: Four CBRMs failed during post manufacturing checkout. Failures were determined to be solid state electronics in the $\pm$ 15 Vdc internal power supplies. Noise on the CBRM circuit, possibly while applying trickle charger power, caused the CBRMs to activate in a random and intermittent manner. After modification and rework, all CBRMs retested satisfactorily. PULSER: Several problems were encountered during tests with the pulsers. Spurious output pulses when a constant 28 Vdc was applied to the pulser. This problem was corrected by placing suppression diodes in the output circuit. The output of the pulsers were AC coupled to the input causing a signal applied to the output to be reflected through the pulser to its input. This problem was corrected by installing blocking diodes in the input of the pulsers. SOLAR ARRAY: Tests were performed in accordance with the ATM solar array checkout equipment operators and program manual procedure, 50M51665, to determine the forward Dark V-I characteristics for each of the five panels. Engineering evaluation of the test data indicated that the Dark V-I characteristic curves were acceptable for all panels. POST MANUFACTURING CHECKOUT (PMC)

Table 3.V ATM System Test Summary

UNITS TESTED	FORMAL DOCUMENTS	TEST	SIGNIFICANT REMARKS
PROTO-TYPE	TCRSD 50M02425	PMC	CONTROL AND DISPLAY PANEL: Switching transients caused time changes on the event timer and command outputs from the DAS. Transients were caused by the history plotter forward-off-reverse switch and the integral lighting switching.
PROTO-TYPE	50M05116 TCRSD 50M02425	T-V	Battery cell shorts caused electronics failures in the CBRM. Battery was redesigned to add a protective fuse in series with the battery negative leads and the third electrode was relocated.
			Several random battery volt alerts, regardless of the voltage level to the CBRMs, resulted in a warning circuit redesign.
		T-V	Battery cells exceeded upper limit of +1.54 Vdc during recharge. 17 CBRMs failed to give a battery recharge cutoff signal, causing alerts on the C&D panel. Problem caused by failure of third electrode signals to reach 200 mV at low temperatures, because heaters would not come on until temperature was below 0°C. A design change was incorporated to start heater turn-on at a higher temperature (5°C).
		T-V	Main power leads in the power transfer distributor made contact with a screw holding a fuse module. The resulting short lasted 1-1/2 minutes with a peak current of 260 amperes. All bus voltages decreased to zero for four seconds. The fuse module was rebuilt and x-rayed to verify specified clearances.

Table 3.V (cont.) ATM System Test Summary

UNITS TESTED	FORMAL DOCUMENTS	TEST	SIGNIFICANT REMARKS
FLIGHT	TCRSD 50M0242	PMC	Pulsers commanded from the C&D panel cutoff because of contact bounce of C&D switches. Pulsers were redesigned.
FLIGHT	TCRSD 50M02425	O&C BLDG AT KSC	Verified all electrical power system compatibility, using AM/MDA simulator and S/A simulator.
	KT-1009 Full ATM Power UP/DOWN		Discrepancies experienced during tests: 1) CBRM 702A13 failure, corrected by replacing input filter capacitors on all CBRMs. 2) Watt Hour assembly hold circuitry sensitivity to noise, corrected by adding filters.
	KT-1109	VAB AT KSC	CBRM 702A10 input relay failed to switch from ESE to solar wing position; CBRM was replaced.
	KT0500	LIGHTNING RE-TEST	Lightning re-test was utilized after lightning hit the pad; test indicated that no damage was incurred.

Table 3.V (cont.) ATM System Test Summary

TEST ARTICLE	TIME OCCURRED	REASON FOR TESTING	TEST DESCRIPTION	SIGNIFICANT REMARKS
SWS and its LAUNCH VEHICLE	May 9 to May 14	At 1257 EDT on May 9 1973, the Mobil Launcher 2 lightning mast was struck by lightning. TCRSD imposed retest to assure vehicle and systems integrity.	1. Full retest of launch vehicle under Lightning Retest Plan and Launch Countdown. 2. Abbreviated retest of SWS including; memory check of ATM computer, and functional tests of PCGs, DCS, and TM.	
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Table 3.VI Mission Test Summary

TEST ARTICLE	TIME OCCURRED	REASON FOR TESTING	TEST DESCRIPTION	SIGNIFICANT REMARKS
AM BATTERY	DAY 7 TO DAY 24	Abnormal storage of batteries due to OWS solar array deploy problem.	The 8 batteries in the Skylab Cluster Power Simulator (SCPS) were placed in similar conditions to test alternative recharge procedures. Each battery was held at the same SOC as a corresponding flight unit. The inlet coolant temperature was held to 39 $\pm$ 2^{o}F and V_{OC} readings were taken each day.	Analysis indicated that deployment of Wing 1 by DAY 26 would delete the requirement for special recharge procedures. Test was terminated. All flight and SCPS batteries returned to normal SOC as expected.
COOLANT LOOP/PCG	PRE-SL-3 DEACTIVATION	Shutdown of prime coolant loop due to fluid leak resulting in no backup system/ no DCS command capability during storage and possible loss of AM EPS.	SCPS was used to validate various alternative procedures for complexity, effectiveness, and completeness.	Four procedures resulted: 1) crew SL-3 deactivation, 2) storage DCS command, 3) SL-4 DCS command, and 4) SL-4 crew activation. Procedures were not used as remaining coolant loop did not fail.

Table 3.VI (cont.) Mission Test Summary

TEST ARTICLE	TIME OCCURRED	REASON FOR TESTING	TEST DESCRIPTION	SIGNIFICANT REMARKS
VOLTAGE REGULATOR	DAY 128 to 133	Determine the effect of possible temperatures in excess of 140°F if coolant loop failed as analysis indicated.	Flight type regulator simulating flight mounting and environment was used. Solar array simulator (for Beta = 58.5°) provided input and simulated load received power tests at 8 and 250 watts/regulator were performed.	8-watt test indicated no problem. 250-watt test indicated 140°F redline exceeded. Data adjusted to account for differences between test and analysis conditions correlated within 2%.
SAS-4	DURING SL-3	Simulate postulated course for anomalous current readings.	SCPS reproduced Figure 8.1 conditions. Path 1 only and Paths 1 and 2 simultaneously were checked. Also, the Electrical ground switch on panel 206 was switched to both positions for each test.	Data verified postulated cause even though SCPS fidelity is not considered high in the area of electrical grounds, and vehicle structure paths. Table 3.VIa summarizes test data.
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Table 3.VI (cont.) Mission Test Summary

C2

TEST CONDITIONS			SAS #4 I	REG BUS #1 I
5700 W LOAD (BATTERY IN TRICKLE CHARGE)	AIRLOCK GND	NO SHORT	5.1	43.8
		SHORT	- 0.8	- 40.1
		ΔI	4.3	3.7
	CSM GND	NO SHORT	5.0	43.8
		SHORT	-(-1.1)	- 38.1
		ΔI	6.1	5.7
3400 W LOAD (BATTERY DRAWING PEAK POWER)	AIRLOCK GND	NO SHORT	12.6	22.1
		SHORT	- 7.2	- 16.6
		ΔI	5.4	5.5
	CSM GND	NO SHORT	12.6	22.0
		SHORT	- 7.9	- 17.2
		ΔI	4.7	4.8
5700 W LOAD (BATTERY DRAWING PEAK POWER)	AIRLOCK GND	NO SHORT	12.5	59.6
		SHORT	- 5.3	- 52.4
		ΔI	7.2	7.2
	CSM GND	NO SHORT	12.6	59.7
		SHORT	- 3.7	- 50.9
		ΔI	8.9	8.8

TEST PERFORMED ON 9-14-73

Table 3.VIa SAS 4 Return Wire Short Simulated Test Result Summary

TEST ARTICLE	TIME OCCURRED	REASON FOR TESTING	TEST DESCRIPTION	SIGNIFICANT REMARKS
CSM POWER TRANSFER CIRCUIT	PRE SL-2 LAUNCH	No AM Reg Bus Power Available from OWS SAS.	SCPS used to determine available ATM power and voltage drop to CSM with no AM Reg Bus Power supplied.	Test concluded power transfer was feasible even without AM Reg Bus Power. Rigorous Power Management was required.
ATM BATTERY CAPACITY TEST	AFTER DAY 17	Verify ATM battery capacity (in orbit) telemetry data.	SCPS test run to onboard parametric values.	Telemetry data validated. Adjustments of specific readings recommended.
ATM BATT. CAPACITY TESTS	DAYs 93, 102, 104, 105	Run ground capacity tests in parallel with in-orbit CBRM capacity tests.	Three CBRMs at the SCPS were tested under similar conditions as the flight units.	Ground test batteries did not have same end of test capacity as flight batteries because of different storage/operation history.
CBRM 17	AFTER DAY 24	Identify problems associated with CBRM 17 low output anomaly.	SCPS test conducted on CBRM with both open and low resistance TM returns.	Verified short external to CBRM.
CBRM 3-5 CONNECTION	PRIOR TO DAY 140	Verify concept of operating partially disabled CBRM 3 and CBRM 5 as one good CBRM.	Acquisition of data on bus characteristics and operations under various load and S/A pointing configurations at the SCPS.	Verified concept and connection plug was carried by the third manned mission crew. The plug was not required because of sufficient cluster power capability. The plug was tested at the SCPS.

Table 3.VI (cont.) Mission Test Summary

TEST ARTICLE	TIME OCCURRED	REASON FOR TESTING	TEST DESCRIPTION	SIGNIFICANT REMARKS
CBRM ALERT CIRCUITRY	AFTER DAY 140	Malfunctions onboard for various CBRM alert conditions and flag indications on the ATM C&D console.	The SCPS verified circuit operation under conditions of onboard CBRM anomalies.	Proper reset procedure to extinguish alert light(s) was established.
SPECIAL CLOSEOUT AND POWER DOWN PROC	END OF MISSION	Verify end of mission procedures.	Procedures performed on SCPS.	Procedures verified.
ATM POWER TRANSFER DISTRIB-UTER WIRING	POST ATM SHORT CIRCUIT DAY 84	Investigated possible shorting conditions within the ATM Power Transfer Distributer.	1 Single wire, AWG 16, $2\frac{1}{2}$ ft long with 355 to 362 Amps. Burn-in test. 2. 26 wire bundle, AWG 16, $2\frac{1}{2}$ ft long, one wire loaded. 3. Wire routed and sized identical to flight unit to determine debris scattering.	1 Failure occurred within 3 to 4 seconds. 2. Failure occurred within 3 to 4 seconds with much damage to adjacent wires. 3. Much debris scattering observed.

Table 3.VI (cont.) Mission Test Summary

c. Skylab Caution and Warning System. Verification of the Caution and Warning System design requirements was successfully completed during the course of the testing program. The testing phase on the flight hardware employed a comprehensive program of tests. These tests began at the component level, in-house and at vendor facilities, and continued through module interface, systems, systems interface, and systems integration testing. Completion of the testing program was accomplished at the launch site.

(1) Contractor Tests. A large part of the system consisted of various types of sensors supplied by outside vendors who were required to verify conformance to the contractor component Specification Control Drawings (SCD). All sensors were required to pass in-house PIA tests as documented in SEDR D3-20, the Preinstallation Acceptance Tests for the Instrumentation System.

Contractor manufactured equipment was also tested per SEDR D3-20. This equipment included the C&W instrumentation packages and the signal conditioner converters. The individual printed circuit card assemblies were testing prior to installation in the instrumentation packages. PIA tests on the C&W unit and high level audio amplifier were performed at the manufacturing facility. Other assemblies such as the parameter display panel, switch and circuit breaker panels, and associated wire bundles were subjected to manufacturing mechanical and electrical checks and inspections prior to integrated system level testing. The system level test flow utilized to verify the performance of the C&W System is shown in Figure 3.4.

During systems evaluation testing, SEDR D3-N70, C&W System input/output signal handling, sensor trip point levels, and compatibility with other systems (i.e., audio, TM, ECS, EPS, DCS, and coolant) were verified. C&W interface parameters were checked during the systems assurance test, SEDR D3-E72. This test also verified AM/MDA C&W functions end-to-end and supported all AM/MDA systems in an EMC check. AM/MDA C&W interfaces were rechecked per SEDR D3-E76, after installation of MDA equipment that arrived late. Simulated flight test, SEDR D3-E75, Volume 1, permitted activation, monitoring, and power down of the C&W System in the manner planned for the mission. Further EMC checks were supported by the C&W System as a part of this test. During the altitude chamber test, SEDR D3-E73, the C&W System was checked for proper responses to simulator inputs during an unmanned run, and functionally checked for visual and audio indications at simulated altitude by the flight crew. Prior to shipment, the EREP was reinstalled, and manned orbital mode and EMC tests were repeated as a part of an abbreviated simulated flight, SEDR D3-E75, Volume II.

SYSTEMS VALIDATION
26 NOV 71 TO 7 JAN 72
SEDR D3-N70

- SYSTEMS TESTS, AM VERTICAL
  - EQUIPMENT WITH AM WIRING
  - AM VEHICLE INTERFACES WITH ATM, MDA, OWS & CSM SIMULATORS
- C&W SYSTEM EMPHASIS:
  - INPUT/OUTPUT SIGNAL HANDLING
  - SENSOR TRIP POINT LEVELS
  - COMPATIBILITY WITH OTHER SYSTEMS (AUDIO, TM, ECS, ELECTRICAL, DCS AND COOLANT)

SYSTEMS ASSURANCE
28 MAR 72 TO 16 APR 72
SEDR D3-E72

- SYSTEMS TESTS, AM/MDA MATED
  - AM/MDA INTERFACE CIRCUITS
  - AM/MDA EQUIPMENT END TO END
  - SIMULTANEOUS ALL SYSTEMS OPERATIONAL COMPATIBILITY
  - REVALIDATION OF DISCONNECTIONS
- C&W SYSTEM EMPHASIS:
  - AM/MDA FUNCTIONAL END-TO-END
  - ALL SYSTEMS EMC SUPPORT
  - PARAMETERS CROSSING INTERFACES

AM/MDA INTERFACE
8 MAY 72 TO 3 JUN 72
SEDR D3-E76

- RETEST OF AM/MDA INTERFACES AND EQUIPMENT AFTER ARRIVAL OF LATE MDA EQUIPMENT

SIMULATED FLIGHT, VOL. I
6 JUN 72 TO 20 JUN 72
SEDR D3-E75-1

- SYSTEMS OPERATION TO SIMULATE INFLIGHT MODES AND SEQUENCES
- EMC TESTS:
  - CRITICAL CIRCUIT MARGINS
  - RADIATED SUSCEPTIBILITY
  - NOISE IN RECEIVER PASSBANDS
  - BUS TRANSIENTS AND NOISE
- C&W SYSTEM EMPHASIS:
  - FUNCTIONAL COMPATIBILITY AND EMC TEST SUPPORT
  - ORBITAL ACTIVATION, MONITORING OF SYSTEMS, AND POWER DOWN

ALTITUDE CHAMBER
11 JUL 72 TO 14 JUL 72
SEDR D3-E73

- CREW AND EQUIPMENT OPERATION WITH AM/MDA AT ALTITUDE
- C&W SYSTEM EMPHASIS:
  - FUNCTIONAL CHECK BY FLIGHT CREW
  - VERIFIED PROPER OPERATION OF MONITORED SYSTEMS AT ALTITUDE
  - PROPER RESPONSES TO SIMULATOR INPUTS DURING UNMANNED RUN
  - CORRECT VISUAL AND AUDIO INDICATIONS DURING MANNED RUNS

SIMULATED FLIGHT, VOL. II
4 SEPT 72 TO 13 SEPT 72
SEDR D3-E75-2

- REPEAT OF MANNED ORBITAL MODE AND EMC TESTS AFTER RETURN OF EREP

SHIP

Figure 3.4 Caution and Warning System Test Flow (Contractor Facility)

(2) Problems and Solutions. Testing of the C&W System identified the following discrepancies:

(a) Alarm Tone Variations in Frequency and Quality. The caution and warning alarm tone quality varied, became less clear, and changed in frequency during system validation. Troubleshooting indicated an intermittent condition having the effect of a short on the C&W System High Level Audio Amplifier No. 2 output. The circuit was monitored during subsequent testing. During simulated flight the tone degradation reoccurred. The C&W System High Level Audio Amplifier (S/N 100) was removed from the vehicle. A functional test was then performed which verified that the system No. 2 output was defective. Unit S/N 101 was subjected to the same functional bench test, met all requirements and was installed on the vehicle. S/N 100 was found to contain resistors having incorrect values installed in the No. 2 subsection of the amplifier. All additional units were verified to have the correct parts installed. The discrepant parts in S/N 100 were causing intermittent operation of the short circuit protection circuitry which resulted in the changes in tone amplitude and frequency.

(b) Erratic Gas Flowmeter T/M Parameter. During system validation, gas flow sensor parameters F205, F209, F210 & F211 had erratic outputs and indicated below normal flow rates. Investigation of this condition indicated that the flowmeters had improper shielding. In addition, the OWS gas interchange sensor (Parameter F205) was improperly located in the duct. The RF type shielding was changed to audio shielding on all four gas flow sensors and the OWS gas interchange sensor was relocated. The C&W gas flow trip points were also lowered to further reduce the probability of false alarms.

(c) Unexpected Caution and Warning Power Light. The parameter identification light illuminated when panel 207 signal conditioner inhibit switch was placed to the enable position during system validation. Laboratory tests found that a short had developed between a component and ground on a printed circuit card assembly. A new circuit card assembly was installed and system retested.

(d) Primary Coolant Low Temperature Below Specification. During system assurance, C&W System temperature parameter trip points were below specifications on the primary coolant low parameter and on the EVA 1 and EVA 2 inlet temperature low parameters. The C&W instrumentation package trip points were found to be lowered by the presence of 2 to 4 MHz noise observed between vehicle structure and the DC returns from the DC-DC converters to the instrumentation packages. The problem was successfully resolved by the addition of jumper plugs to both C&W signal conditioner (instrumentation) packages. The jumper plugs contained capacitors installed between the pins connected to structure and the DC power returns. These capacitors shorted the conducted noise.

(e) Noise Perturbations on MDA Temperature Parameters. Various MDA temperature parameters experienced up to 15 counts of noise at random intervals on the T/M outputs during altitude chamber tests. Testing revealed the C&W unit internal DC-DC converters were generating the noise due to their electronic switching action. The noise was coupled into the MDA temperature parameter T/M lines in the vehicle wire bundles. Capacitors installed between the C&W telemetry output signal return lines and chassis ground and between the C&W telemetry output signal return lines and chassis ground and between the C&W subunits signal ground and chassis significantly reduced the noise coupled into the MDA temperature parameters. Modifications were performed on all C&W units to incorporate the internal capacitors.

(f) No Secondary Coolant Flow Alarm. A C&W System alarm did not occur when the secondary coolant pump A switch was placed to on during altitude chamber tests. The problem was isolated to a reed switch failure. The pump containing the defective reed switch was removed and replaced.

(g) Two C&W System Alarms not Recallable from Memory. During descent from altitude, two separate C&W System alarms occurred which could not be recalled from memory to be identified. Retest and troubleshooting at ambient altitude after the run could not repeat the condition. Memory recall cicuitry functioned correctly in all cases. During crew debriefing, it was stated that following the first alarm the memory clear switch had been inadvertently actuated prior to attempting memory recall. The crew believed the memory recall sequence was performed correctly after the second alarm; however, the parameter identification light did not illuminate. Since the problem could not be repeated it was categorized as an unknown condition. The problem never reoccurred during subsequent testing.

(h) Rapid Delta P Alarms from RFI. The rapid delta P C&W alarm triggered at various times during simulated flight EMC tests. It was found that the rapid delta P sensors were susceptible to low frequency variations in RF field strength of VHF transmitters. False alarms occurred as a result of the sensor detecting the RF variations induced on the sensor leads. Problem resolution was accomplished by installing new wire bundles, which incorporated RF filtering and shielding, between the sensors and vehicle pressure bulkhead.

(i) Secondary Coolant Temperature Low Alarm. A secondary coolant temperature low alarm occurred during simulated flight, Vol. II. The sensor was found to have a low resistance short to structure. The defective sensor was removed and replaced.

(j) Lack of EVA No. 2 Pump Delta P Alarm. EVA No. 2 pump delta P C&W alarm did not occur with zero pressure on SUS loop No. 2. The problem was determined to be a defective sensor which was remaining open. The sensor was removed and replaced.

(3) Launch Site Testing. Launch site test requirements for the C&W System are defined in Report MDC E0122, Test and Checkout Requirements Specifications and Criteria for use at KSC, and by the Skylab Integrated System Test Checkout Requirements and Specifications, Document No. TM012-003-2H. Tests per these requirements were successfully accomplished during the system level and integrated testing performed at KSC.

One significant C&W System problem occurred during KSC testing. During the AM/MDA/CSM interface test, an inadvertent rapid delta P alarm could not be correlated with vehicle activity. The new wire bundles, mentioned in paragraph (h) above, had been installed. Duplication of the problem was attempted at St. Louis. Test results confirmed that the alarm occurred due to fluctuations that existed in the rate output section of the delta P sensor. The erroneous rate output was found to be a function of internal interference in the sensor resulting from the effect of two harmonics heterodyning. The transducer oscillator and the DC-DC converter oscillator, both internal to the sensor, were generating the harmonics. The sensors were modified to synchronize the DC-DC converter oscillators. In addition, filter capacitors were added between the +28 VDC return and signal return to chassis, and a zener diode was installed between the +28 VDC input lines to prevent transients on the sensor voltage regulator inputs.

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4. Design Modifications

During the course of design, analysis, and test activities, for chargers, batteries, voltage regulators, solar arrays, and distribution, several hardware modifications were imposed. Table 4-I summarizes those considered significant to the success of the flight hardware operations.

Although the basic battery type was selected because of a good flight history and expected minimum development risk, modifications became necessary for the reasons indicated on the table.

In addition to the listed modifications, one design deviation was granted for the AM EPS. That was against the ICD 40M35659-3 "ATM/AM Electrical Interface." In this case, the 12 AWG power feeders between the AM transfer bus and the ATM bus were designed using non-twisted wires. This violated the ICD which called for twisted pairs. Since the cost and schedule impact of conforming to the ICD was not considered warranted by MSFC, a request for deviation was approved.

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ITEM	REASON FOR MODIFICATION	MODIFICATION USED TO SATISFY CONDITION	SIGNIFICANT REMARKS
CHARGER			
1. REDUNDANT AHM	Increase reliability, based upon analysis.	Include redundant AHM	Required complete repackaging
2. AHM USAGE	Redundancy.	a. Both AHMs to be simultaneously powered. b. Provided onboard meter display. c. Provided charge mode switching to maintain voltage limit charge mode capability if required.	Originally the second AHM was intended only for ground monitor.
3. INPUT VOLTAGE (125 Vdc MAX)	Imposed increase from 110 Vdc input voltage from OWS solar array based upon thermal analyses.	Use higher input voltage rated power transistors and capacitors.	This constraint significantly impacted charger development.
4. PEAK POWER TRACKER	Development testing revealed occasional load transient induced anomaly in tracker operation.	Circuitry change to closed loop response of the peak power tracker circuit.	Condition occurred under some load/ solar array conditions only.

Table 4.I Design Modification Summary

AM

ITEM	REASON FOR MODIFICATION	MODIFICATION USED TO SATISFY CONDITION	SIGNIFICANT REMARKS
5. BIAS CONVERTER	Failure during vendor testing. Analysis revealed overstress of main power transistor from initial turn-on high voltage.	Change power transistors in bias converter circuit and modify power transistor drive circuitry.	
6. MOISTURE SEAL	Failure to pass humidity test.	Add moisture seal to all mating surfaces of removable cover plates.	
7. ARM RESET CIRCUIT	Design found susceptible to noise generated by test equipment during temp/altitude testing.	Include a filter capacitor.	
8. TRICKLE CHARGE CURRENT AND RETURN FACTOR	MSFC direction to reduce current from 1.5 ± 0.5 to 0.75 ± 0.5 amperes and return factor by 4%.	Replace all, (30) power module and (12) ampere-hour-meter, resistors.	Charger qualification status unaffected. All flight units redesignated as -11 from -5.

Table 4.I (cont.) Design Modification Summary

AM

ITEM	REASON FOR MODIFICATION	MODIFICATION USED TO SATISFY CONDITION	SIGNIFICANT REMARKS
9. OPERATIONAL AMPLIFIER	Failure of four units in their voltage control circuitry. Analysis revealed input junctions damaged by excessive input current. Exact cause of failure not identified.	Current limiting resistors were added in series with the input leads.	In each case failure occurred during unpowered conditions such as trouble-shooting, dielectric test, etc. Charger qualification status unaffected. Flight Units redesignated as -17 from -11. No reoccurrence of the condition.
BATTERY			
1. CELL PLATE	Shorting cells detected during conditioning activity. Analysis indicated inadequate clearance between top of one plate and tab on adjacent plate.	Modify cell plate geometry to provide adequate clearance.	Condition presented potential life limiting situation in the event of misalignment or plate shifting after cell assembly.
2. CASE MATERIAL	Unacceptable temperature gradients observed during acceptance testing.	Change battery case material to aluminum from magnesium to reduce temperature gradients.	High temperatures were detrimental to long cycle life.

Table 4.I (cont.) Design Modification Summary

AM

ITEM	REASON FOR MODIFICATION	MODIFICATION USED TO SATISFY CONDITION	SIGNIFICANT REMARKS
3. CELL HOLD DOWN	Failure of cells during testing and analysis which revealed both tab clearance problem and positive plate physical growth which was restricted by nylon cell hold downs.	Establish new design configuration without hold downs. Provision for monitoring cell voltage was also included at this time.	Plate deformation and interplate pressure points caused premature cell failure. Testing without cell hold downs verified they could be removed.
4. PACK ASSEMBLY	One of two qualification units failed at 3028 cycles. Workmanship was inconsistant with regard to tab shaping and pack assembly.	Limited remake of flight units was authorized with emphasis on quality.	Units previously assembled could not be validated. A special tab combing tool was used and was the major improvement required.
VOLTAGE REGULATOR			
1. POWER TRANSISTOR OSCILLATION	Production testing revealed occasional hi frequency oscillation of power transistors at voltages above 90 volts.	Include a small inductance in the base lead of power transistors.	Condition could result in excess heating and destruction of the unit.

Table 4.I (cont.) Design Modification Summary

AM

ITEM	REASON FOR MODIFICATION	MODIFICATION USED TO SATISFY CONDITION	SIGNIFICANT REMARKS
2. BIAS CONVERTER	Failure during acceptance testing. All power modules were inoperative. Analysis revealed faulty ± 12 volt bias converters caused by marginal component tolerances and high input voltages.	Change values of pertinent components in each bias converter circuit and add test points in each unit for operation verification.	Flight units were redesignated as -9 from -3
SCR CIRCUIT	Welding of charger relay contacts during spacecraft system testing. Analysis revealed cause to be severe current transients (1400 amps) during switching from normal to bypass positions which lasted for several hundreds of microseconds. Review of PCG circuits indicated similar conditions possible in batt. relays. Transients	Include SCR circuits across each battery and charger relay contact to shunt high current transients around relay contacts thus eliminating damage.	SCR was triggered "ON" prior to contact closure and "OFF" by being shorted by relay closure. Fuse fault protection was included.

Table 4.I (cont.) Design Modification Summary

AM

ITEM	REASON FOR MODIFICATION	MODIFICATION USED TO SATISFY CONDITION	SIGNIFICANT REMARKS
	of 400 amps for one millisecond could exist. Actual tests verified these contacts would weld after repeated operation.		
SOLAR ARRAY			
1. CELL INTERCONNECTORS	Enhance integrity of the design to survive test, launch, and mission environments.	Increase stress relief loops on interconnectors.	Inspection after each test and flight performance verified the effectiveness of the modifications used. Critical parameters were identified and concentrated on. In place cell repair techniques were demonstrated.
2. CELL BONDING		Use metered adhesive dispensing to assure uniform and adequate bonding.	
3. MANUFACTURING CRITERIA		Prepare visual aids and simplify tooling to assure consistent quality.	
4. WING SECTION WIRING	Detected abrasion during deployment test SA-2.	Installed wiring on stabilizer beam, added protective grommets and sleeving to indicated areas.	Condition corrected.

Table 4.I (cont.) Design Modification Summary

AM/OWS

ITEM	REASON FOR MODIFICATION	MODIFICATION USED TO SATISFY CONDITION	SIGNIFICANT REMARKS
5. SOLAR CELLS/MODULES	Improve reliability of solder contacts.	Criteria and control of module manufacturing processes were improved.	Effectiveness verified by flight performance low degradation.
6. SOLAR CELL MODULE	Cope with imposed dynamic shadowing during unconstrained maneuvers.	Utilized a concept where 4 individual 154 series cell strings are parallel only at their end point.	Effectiveness verified by flight performance low degradation.
7. POTENTIOMETER	Need to know percent wing sections were deployed.	Include a potentiometer on each wing section.	Effectiveness verified by detection of percent deployment during failure to deploy anomaly for OWS solar array wings and flight data on solar array performance.
8. POWER DISTRIBUTION SYSTEM	Satisfy flammability requirements of MSFC-SPEC-101A.	a. Use Raychem NBG convoluted tubing for localized breakouts of wiring. b. Reduce routing path length to minimize weight. c. Standardize parts. d. Compartmentize wiring.	Effectiveness verified by flight performance.

Table 4.I (cont.) Design Modification Summary

AM/OWS

ITEM	REASON FOR MODIFICATION	MODIFICATION USED TO SATISFY CONDITION	SIGNIFICANT REMARKS
9. METER CIRCUITS	Meters tend to stick at low end.	Add bias circuit.	
10. ELECTRICAL UMBILICAL	New requirement for 30 A relays and talkback circuits for deadfacing and verification thereof, and provide for emergency power down.	Add wiring between OWS umbilical connectors and AM/OWS. Add 32, 30A relays and talk[illegible]k circuits.	Emergency power down capability was via ESE commands.

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Table 4.I (cont.) Design Modification Summary

AM/OWS

ITEM	REASON FOR MODIFICATION	MODIFICATION USED TO SATISFY CONDITION	SIGNIFICANT REMARKS
ATM NETWORKS	a. Allow redundant ATM power "on" command after liftoff.	a. DCS command added to re-initialize all CBRMs after liftoff.	1) Since no TM available until after S/A deployed, a backup command was sent to turn on CBRMs in case they were somehow shutoff during boost.
	b. ATM power off circuit would not allow shutdown of CBRMs and subsystems.	b. One second timer replaced by two 300 millisecond timers.	
	c. ATM - Power "off" switch would not disconnect ATM power system from AM transfer bus.	c. Added control circuit across AM/ATM interface.	
	d. Automatic turn-on of ATM sub-buses.	d. Added circuits from IU automatic sequencer.	
AM NETWORKS	Optimize the design for dual bus configuration.	Change from motor switch to power relays in power transfer circuit.	

Table 4.I (cont.) Design Modification Summary

ATM/AM

ITEM	REASON FOR MODIFICATION	MODIFICATION USED TO SATISFY CONDITION	SIGNIFICANT REMARKS
SOLAR CELL MODULE			
Interconnectors and Buses	During thermal cycling series turnaround buses and interconnectors on modules broken after repeated cycling.	Turnaround buses bonded to substrate and cell interconnectors were redesigned to include long stress relief loops and improvement of soldering techniques.	Additional adhesives support reduced flexing during temperature cycling thus reducing open-circuit probabilities caused by work-hardening/fatigue.
PULSERS			
Circuitry	Spurious pulses due to transients.	Redesigned pulser circuit for compatibility with C&D panel switches, and to eliminate transients.	During PMC and T-V testing extraneous commands were found to have been issued from pulser circuitry to the ATM hardware.
WATT-HOUR ASSEMBLY			
Return Path	Return grounded to case during prototype qual test.	Changed an electrolytic capacitor/diode circuit.	
ATM C&D CONSOLE			
1. Panels	Panel Density - In flux of design changes	Utilize smaller rotary switch skirts and knobs than those on Apollo. Shared nomenclature where common functions exist between two rotary switches.	

Table 4.I (cont.) Design Modification Summary

ATM

ITEM	REASON FOR MODIFICATION	MODIFICATION USED TO SATISFY CONDITION	SIGNIFICANT REMARKS
		Narrower toggle switch tunnels.	
2. Panel Nomenclature	Wet-to-dry configuration relocating console into MDA.	Deletion of: S/A pyro controls, C&W, vehicle attitude control function from manual pointing controller; added TACS controls.	
		Mod to power subsystem C&D.	
CBRM			
1. Input Filter	a. Tantalum wet slug capacitors were shorting during system sim test.	a. Relay module and related circuitry installed to eliminate reverse biasing of capacitors.	
	b. Failure of capacitor during KSC testing.	b. Use tantalum foil Capacitor	Tantalum foil capacitors were used successfully.
2. Internal Power Supply	+15 VDC internal power supply transistors burned out.	Replaced transistors and diodes with higher rated transistors and diodes.	
3. Command and alert circuitry	Transient and EMI Susceptibility	Noise suppression circuits added.	

Table 4.I (cont.) Design Modification Summary

ATM

ITEM	REASON FOR MODIFICATION	MODIFICATION USED TO SATISFY CONDITION	SIGNIFICANT REMARKS
4. Resistor Heater	Increase operating temperature range from (0°F to -10°F) to (0°F to +10°F).	Change resistor values.	
BATTERY			
1. Controls	Improve response of third electrode signal and assure rapid and complete recombination of normally evolved O_2 and H_2.	Addition of fourth electrode.	
2. Negative Plate Surface	Maintain useful capacity for longer period of cyclic operation.	Increased negative/positive ratio from 1.35 to 1.45.	
3. Cells	Short to case during 1-V.	Fuse added in series with battery negative leads - new AB 12G cell also used.	New cell changed position of third electrode and provided uniform pressure over entire cell area.
4. Negative Circuitry	Protect against short circuit to battery case.	Add 2, 30A fuses in parallel in the battery return lines.	

Table 4.I (cont.) Design Modification Summary

ATM

ITEM	REASON FOR MODIFICATION	MODIFICATION USED TO SATISFY CONDITION	SIGNIFICANT REMARKS
MDA INTERNAL (GENERAL ILLUMINATION) LIGHT ELECTRONICS	Lights exceeded the maximum current specified for operating in the "low" mode.	The electronics in the light assembly was modified to reduce current requirement.	All MDA interior lights were replaced with the modified lights, prior to flight.
INVERTER LIGHTING CONTROL ASSEMBLY (I/LCA)	A thermal output study and analysis of the C&D console and I/LCA resulted in a recommendation to mount the I/LCA external to the MDA.	The I/LCA and interconnecting circuitry was modified to permit installation of the I/LCA on the forward conical section of the MDA on the L-Band antenna truss. The I/LCA redesign incorporated two ninety-watt heaters.	
BACKUP I/LCA	To provide redundant power source for the ATM C&D console lighting.	A backup I/LCA was designed using available qualified components and installed internal to the MDA. The backup I/LCA would be connected to the C&D lighting by use of patch plugs in the event of failure.	The backup design did not provide variable lighting capability for the integral and numeric lighting.

Table 4.I (cont.) Design Modification Summary

MDA

ITEM	REASON FOR MODIFICATION	MODIFICATION USED TO SATISFY CONDITION	SIGNIFICANT REMARKS
EARTH RESOURCES EXPERIMENT PACKAGE (EREP)	The late incorporation of EREP into the MDA resulted in rather extensive modification to the MDA system.	The MDA power and instrumentation systems were modified to incorporate the EREP.	The off solar inertial pointing (Z-LV) for EREP maneuvers imposed a reduction in power capability (due to off sun pointing) and an increased electrical load. All imposed loads were satisfied by design and certified by test and analysis prior to flight.
AM/MDA CSM POWER TRANSFER WIRE	Increase number of wires from the AM transfer bus to the CSM/MDA interface to meet the minimum requirement of 27.4 volts at this interface.	Increased the wires from the AM transfer bus to the CSM/MDA interface as follows: a) Increased from 5 to 10# 10 AWG on each positive bus and from 8 to 18# 10 AWG on the return bus in the AM. b) Increased from 5 to 10# 12 AWG on each positive bus and from 8 to 18 #12 AWG on the return bus in the MDA.	The AM/MDA power system power transfer voltage drop was verified during test at KSC and during each manned mission.
MDA/CSM CONTINGENCY POWER CABLE	A redundant cable was required in case of malfunction of power transfer cable.	A drag through cable was designed to accommodate the additional wires at the CSM/MDA interface.	This cable also provided a redundant power connection at this interface.

Table 4.I (cont.) Design Modification Summary

MDA

5. <u>Flight System Description</u>.

a. General. The Skylab Cluster required electrical power for life support, housekeeping, experiment operation, instrumentation and communications, and attitude control of the vehicle. This power was used to operate, monitor, and control each subsystem.

The electrical energy was supplied by three complementary, independent, electrical power systems. This description is limited to two of these, namely, the AM/OWS and the ATM electrical power systems. The CSM discussion is beyond the scope of this report. Figure 5.1 illustrates the cluster power sources and their general physical locations.

All Skylab electrical energy was generated from sunlight by photovoltaic solar cell arrays. These direct energy conversion devices collected, and converted visible light into electricity. This power was conditioned, stored, and controlled. It was then distributed to commands, indications, and at a nominal 28 Vdc, to all applied loads. During sunlight conditions, the solar arrays supplied loads directly. However, depending upon orbital inclination angle (Beta), the cluster experienced sunlight periods of various lengths during each orbit, Figure 5.2. During these periods, the stored energy in each system's nickel cadmium batteries which maintained continuous power flow to all loads during night periods, was replenished.

The power conditioning portion of each power system was composed of a battery, battery charger, and voltage regulator. Appropriate control switching for effective management of inputs to various buses was provided on various instrument control and display panels throughout the cluster or by ground control through either DAS for ATM or DCS for AM/OWS, Figure 5.3.

Figure 5.4 is a simplified block diagram of the cluster power distribution and grounding arrangement. Interconnections between buses and module power sharing interfaces are indicated. Figure 5.5 and 5.6 are details of grounding and transfer bus portions of the overall diagram. The two power systems, although independent in design, normally operated in parallel to permit power sharing in either direction. When paralleled, the power system having the highest bus voltage supplied the majority of the total cluster load. The AM/OWS EPS output voltage was adjustable and thus was used to achieve the desired load sharing for both EPSs. During each manned phase, the CSM remained independent until fuel cell depletion, a period of about 20 days. After depletion, the CSM received power from the paralleled power systems until undocking. This occurred by way of a power cable (indicated in Figure 5.4) between the CSM and the MDA. It was installed and removed by crew action during activation and deactivation activities, for each manned phase.

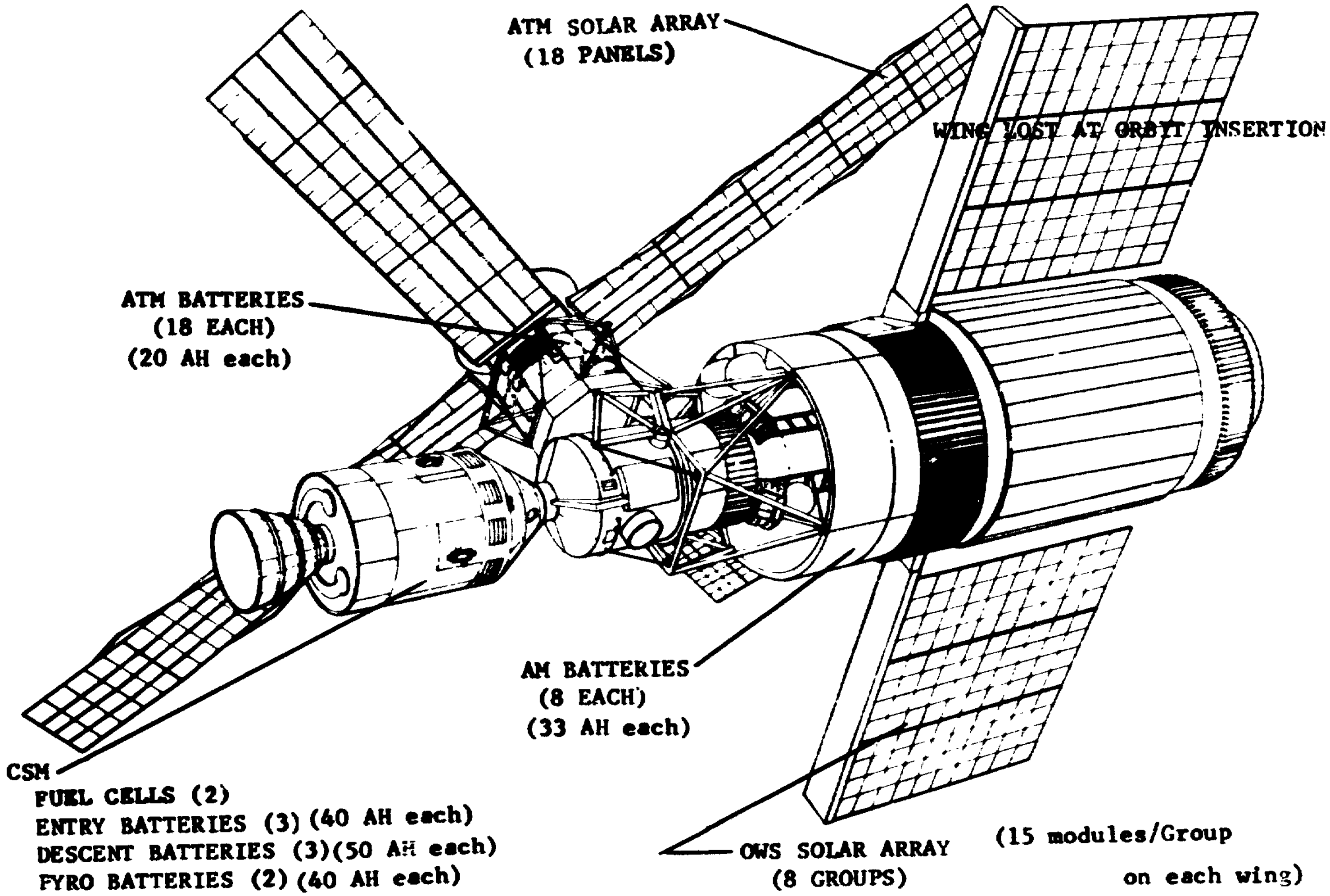


Figure 5.1 Orbital Assembly Power Sources and Locations

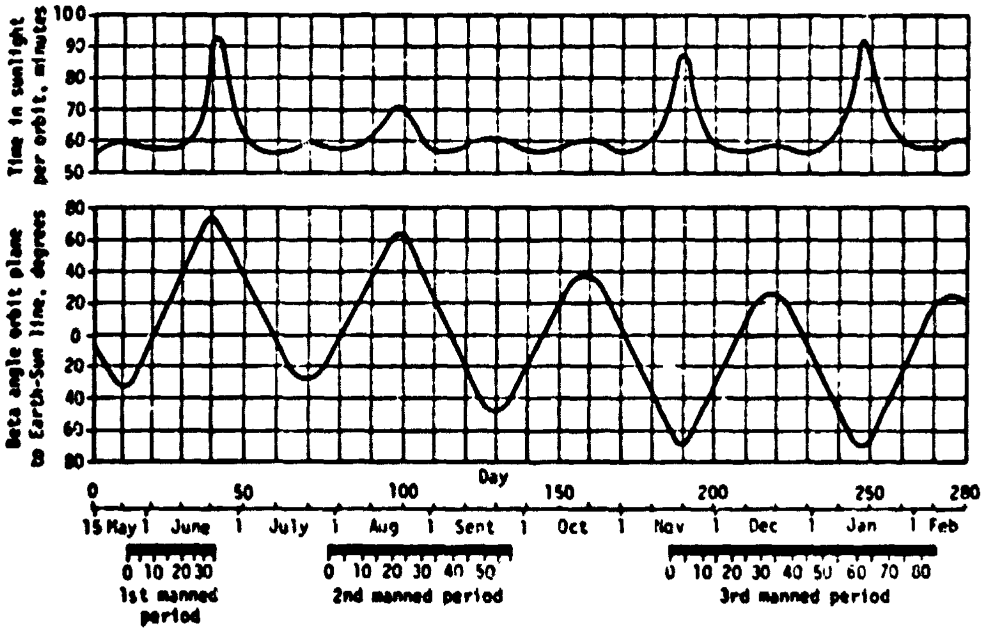


Figure 5.2 Beta Angle History and Sunlight Time

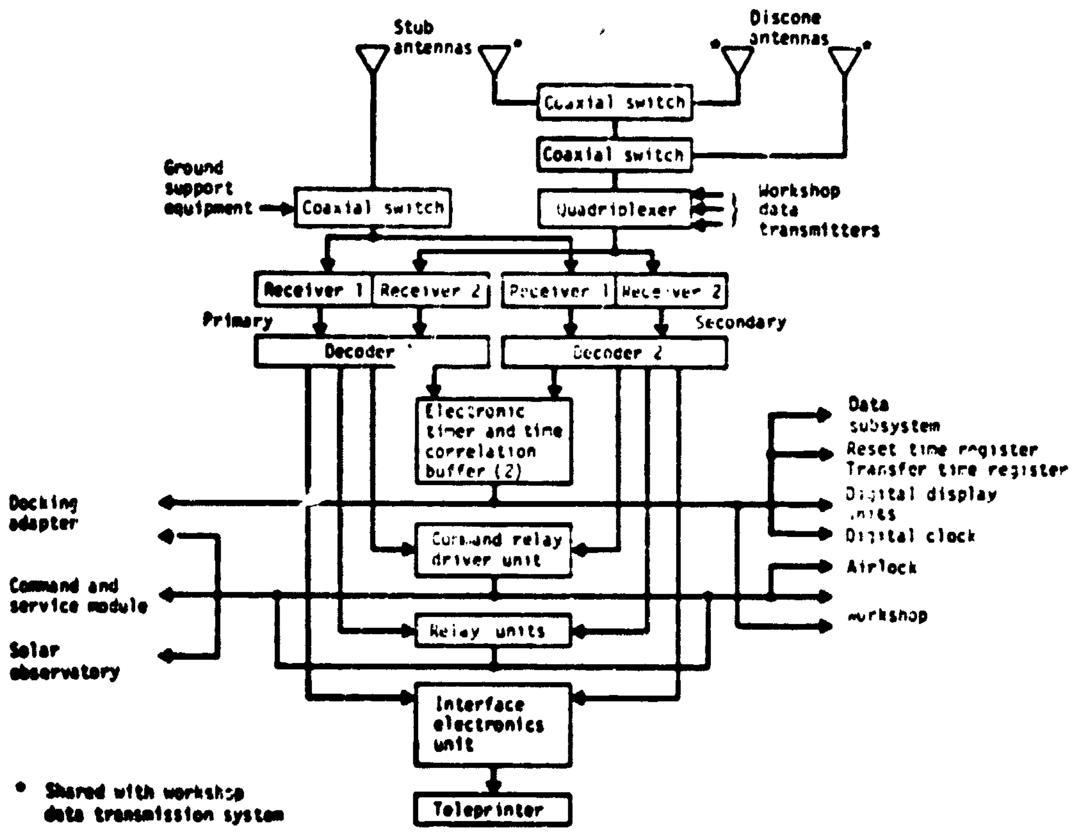


Figure 5.3a Command System used for Ground Control of A EPS (DCS)

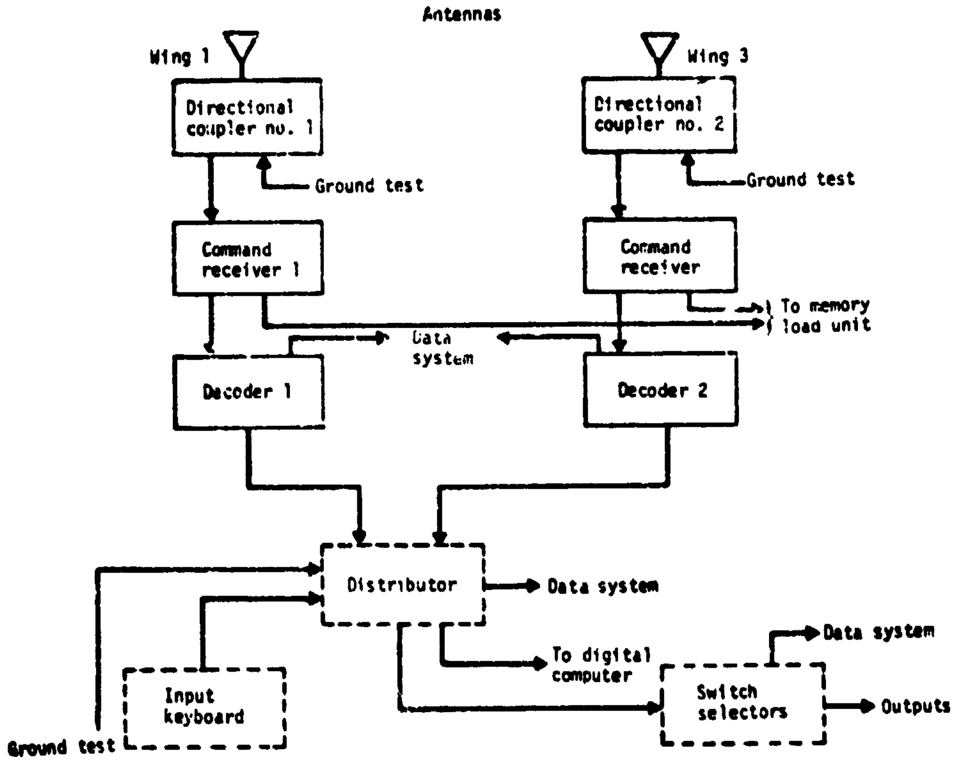


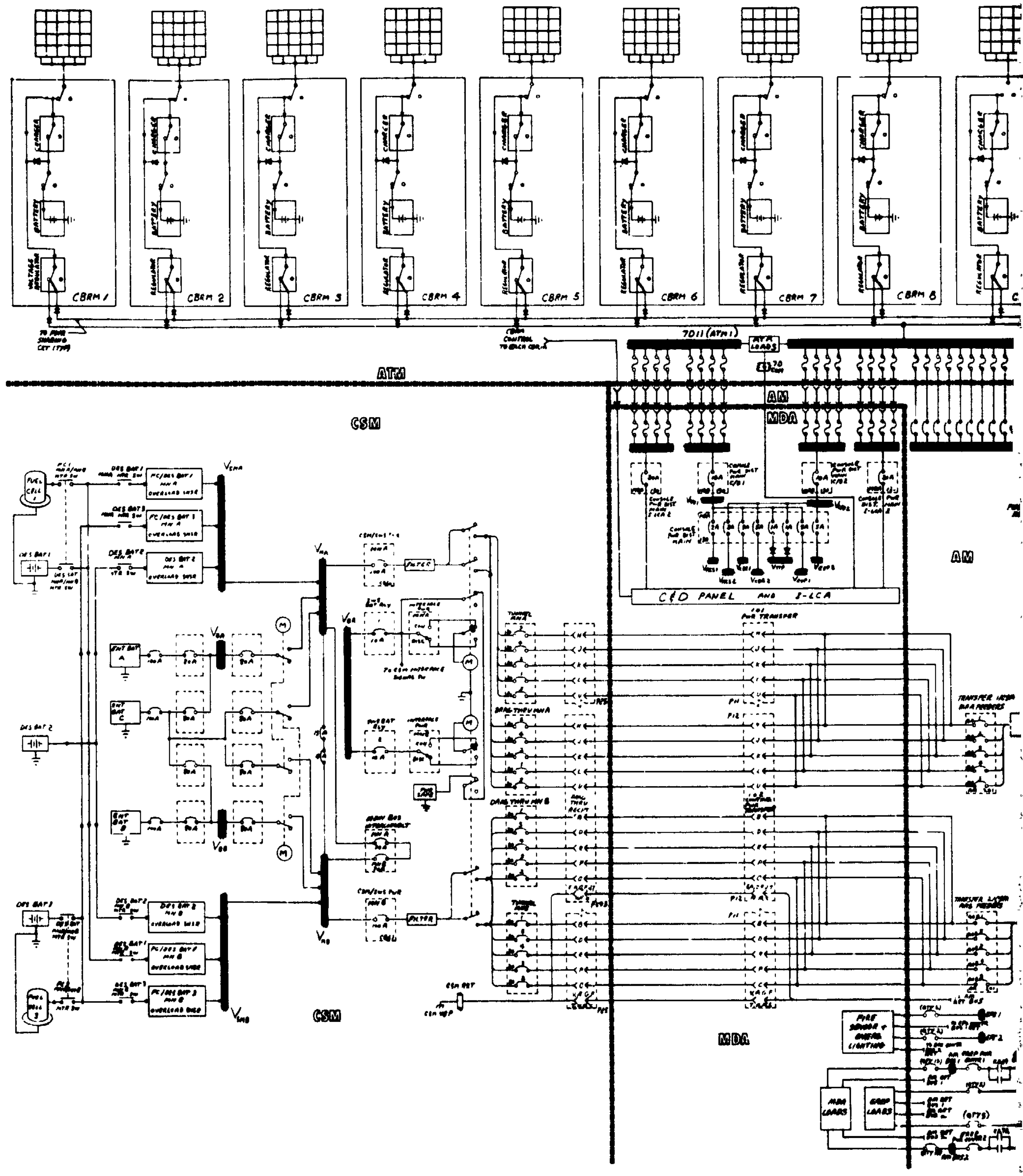
Figure 5.3b Command System used for Ground Control of ATM EPS

FOLDOUT FRAME

1

FOLDOUT

2



FOLDOUT FRAME 2

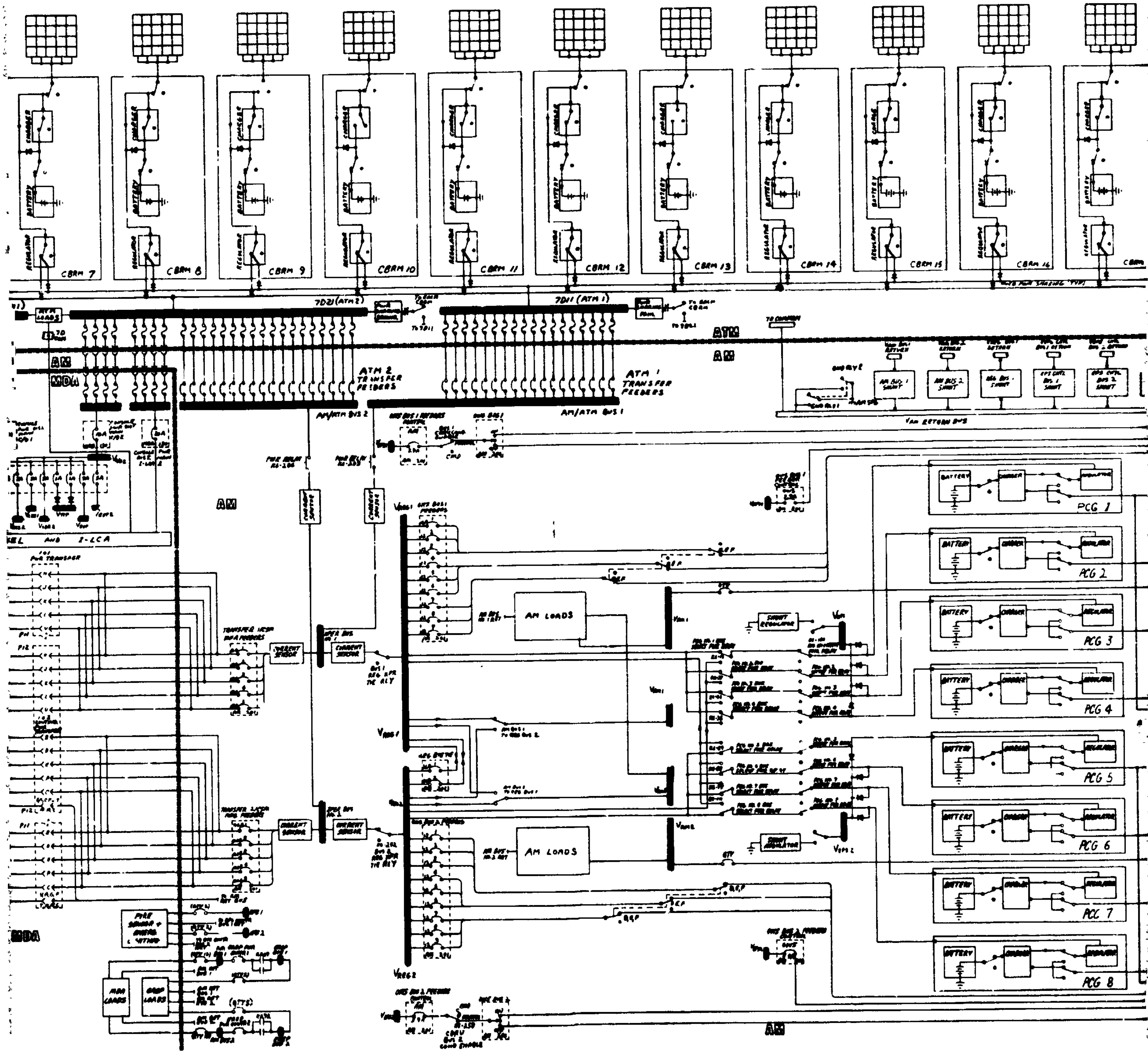


Figure 5.4 Skylab Orbital Assemb

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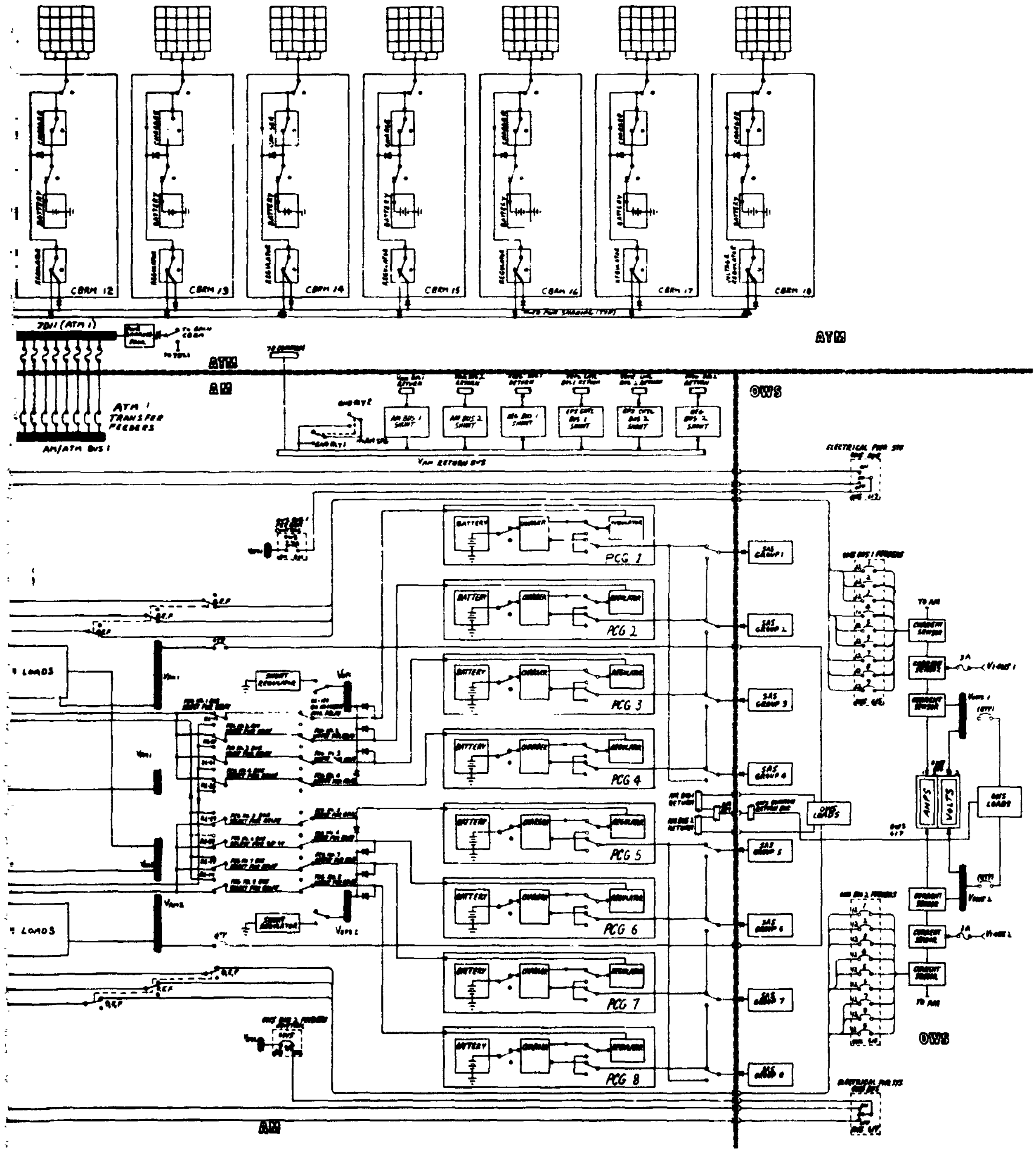


Figure 5.4 Skylab Orbital Assembly EPS Simplified Block Diagram.

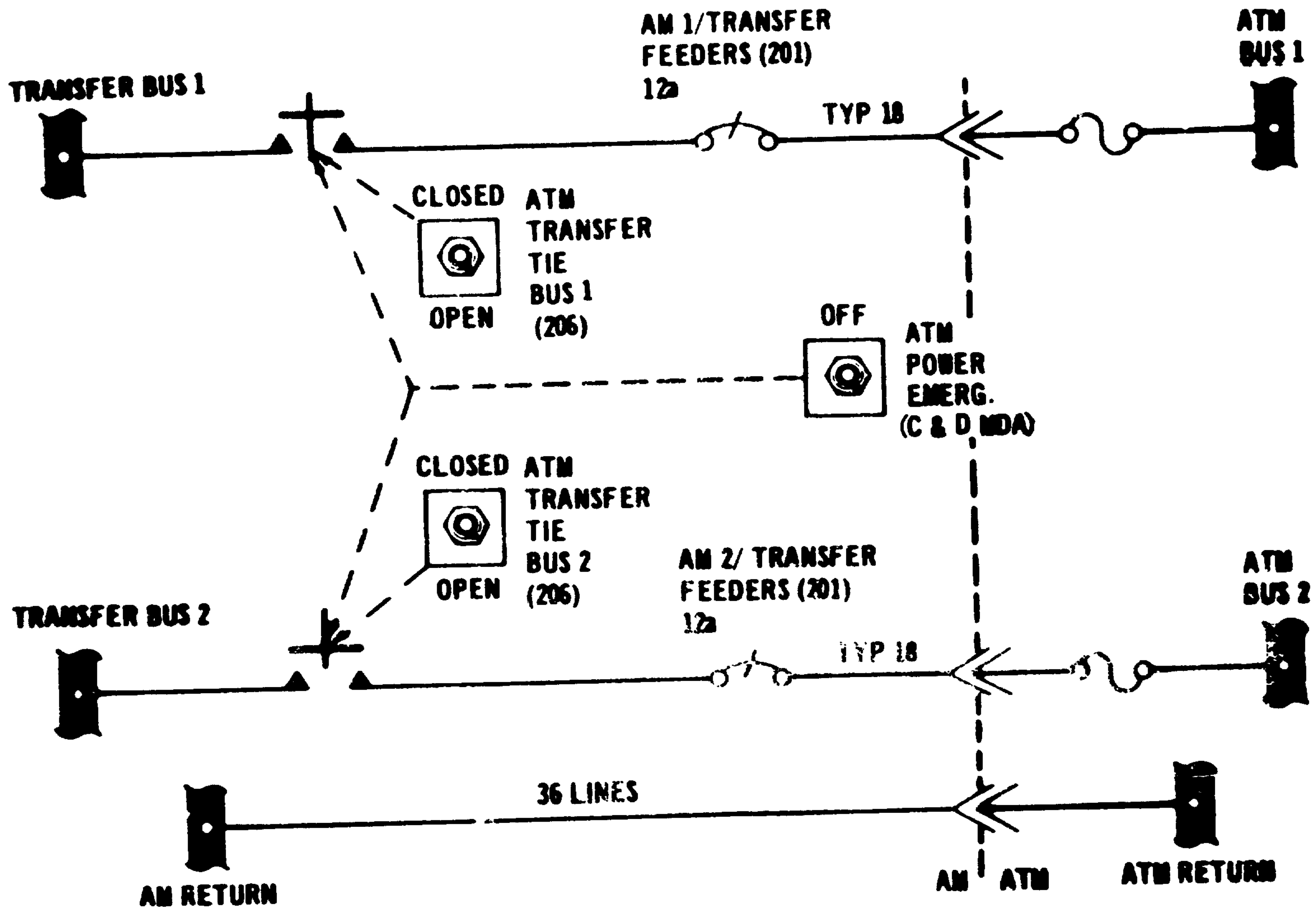


Figure 5.6 AM/ATM Power Transfer Interface

The overall, parallel bus, power distribution system supplied regulated DC power continuously and was controlled by appropriate monitoring of specific parameters displayed by onboard instruments and telemetered to the ground.

Additional power distribution capability existed throughout the cluster for portable equipment by way of utility power outlets.

The major components of each power system were: solar array (8 SAGs for AM/OWS, 18 panels for ATM); power conditioner/energy storage (one for each solar array group); control and display panel assemblies; dual bus distribution; relay panels; and two shunt regulators for AM/OWS. The physical locations of the power conditioning equipment of each subsystem are given in Figure 5.8. The AM/OWS shunt regulators were mounted on the -Y axis under Truss Panel No. 1. Control panel assemblies were located within each module and included onboard controls, displays, circuit breakers (and other protective devices associated with the respective system).

Tracking lights were required to provide each crew with a means of visually locating the SWS during rendezvous at orbital night in conjunction with the Apollo sextant, or with the Crew Optical Alignment Sight (COAS) as a close-range backup. The requirement for these lights was created as a result of a vehicle redesign which eliminated four acquisition lights originally installed on the OWS.

Four tracking lights, two primary and two secondary, were provided. Each light consisted of a flash head and an electronics unit. The four flash heads were mounted on the AM deployment assembly, two on each side of the MDA, near the SWS Y-axis (Figure 5.9a), and the electronics units were mounted on Electronics Module #6. Each light provided a 90° cone of light centered on the SWS +X-axis, with a minimum light intensity of 1000 beam candle seconds. The lights flashed at a rate of 50-65 flashes per minute, with a maximum flash duration of 0.3 millisecond. The primary lights were only synchronized with each other, as were the two secondary lights.

The tracking lights selected were a modified version of the Apollo Program lights. A number of changes were required to the lights to produce the increased light intensity required for the Skylab program. The higher light intensity requirements created certain design problems, such as operating in the corona susceptible region and meeting the requirements of the AM Electromagnetic Compatibility Control Plan.

The operation of the lights also created a personnel eye damage hazard which required specific operational constraints, such as shielding the lights during test operations and turning them off when the CSM was in close proximity to the SWS. A block diagram of the tracking lights is shown in Figure 5.9a. Control of the lights was normally provided by the DCS; however, an onboard switch was available for crew use. Automatic switchover circuitry provided the use of secondary lights in the event of a malfunction in the primary lights. If the secondary lights were selected, this circuitry energized all remaining lights in event of a secondary malfunction.

An alternate means of off control for the tracking lights was provided by the electronic timer Tx function, to provide for termination of operation when the spacecraft was out of range of a tracking station.

The primary and secondary tracking lights were powered from alternate buses. Each electronics unit required 180 watts maximum of unregulated power and supplied 80 watts to the flash head. Docking lights were required to provide the CSM crews with orientation and alignment information during final docking maneuvers.

Initially there were eight (8) docking lights, four mounted on the FAS and four mounted on the MDA, Figure 5.9b. The lights were color coded to aid the crew in orienting the CSM for final rendezvous and docking maneuvers. Subsequently the discone antenna docking lights were added which acted as visual locators for the crew so the antennas could be avoided during fly around and docking maneuvers. The additional capability of powering the white AM docking light from the EVA lighting system existed.

Although the lights were normally controlled via the DCS, an onboard switch provided the capability for crew control in the event of an EVA or a CSM rescue mission. AM busses 1 and 2 each powered half of the docking lights. The individual lights were not redundant since the loss of several lights would not jeopardize docking.

For purposes of clarity and organization, this section separates detailed discussion of Power Distribution from that of power generation. In addition, those discussions will be separated into AM/OWS and ATM.

b. Power Generation.

(1) AM/OWS.

(a) Solar Array. The Solar Array Subsystem (SAS) consisted of two (2) wings, each having a beam fairing and three (3) wing sections. Each wing section contained ten (10) identical active solar panels for a total of 30 panels per wing or 60 panels per system. Two additional panels were included in each wing section to provide spacing between active panels and the beam fairing; one a truss panel and the other a "dummy" panel. A typical SAS wing assembly and location is shown in Figure 5.10a.

Figures 5.10 and 5.11 detail the assembly of solar cell modules. The overall physical description is summarized in Table 5.I. The four

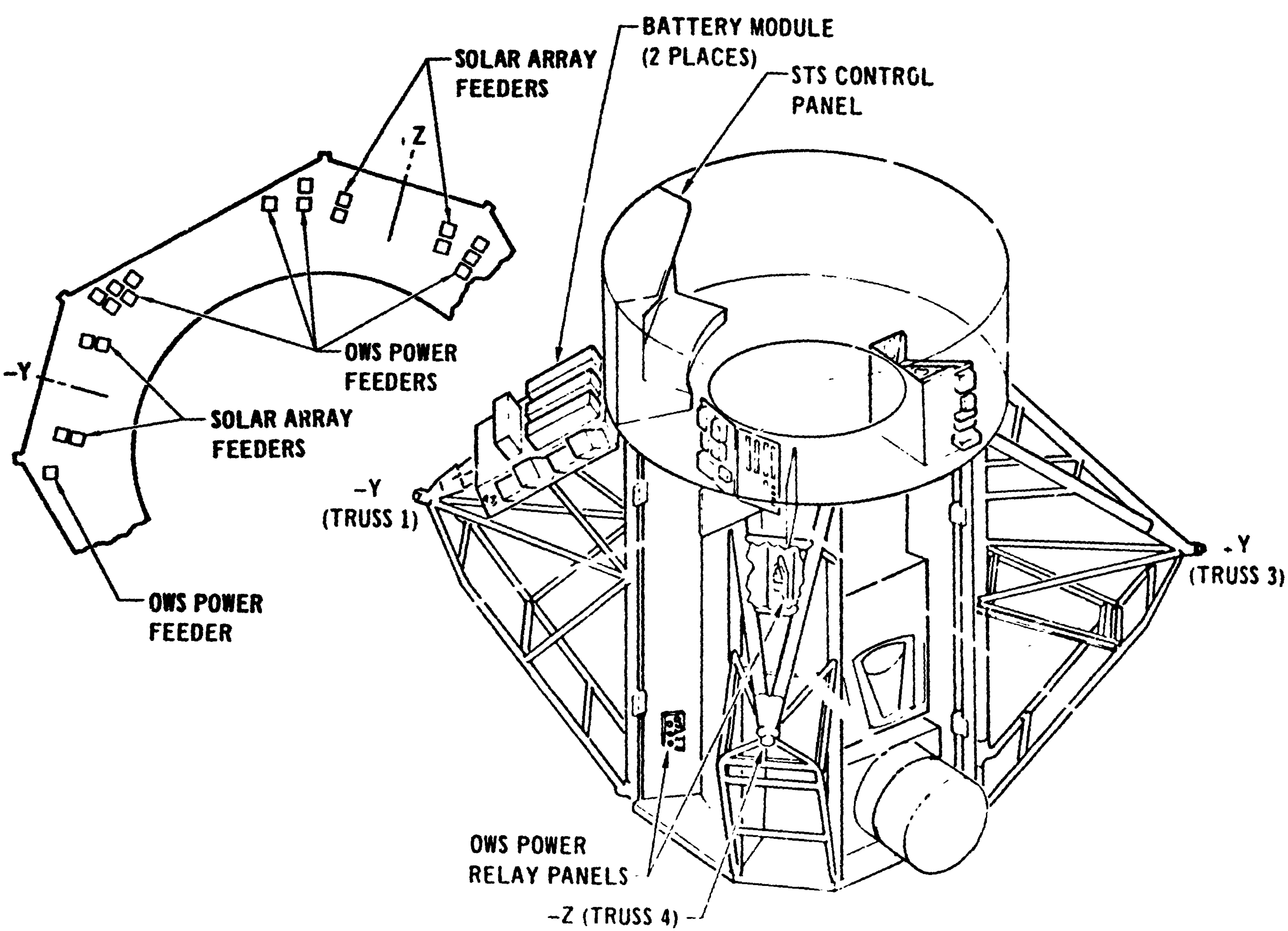


Figure 5.8a AM EPS Equipment Physical Location

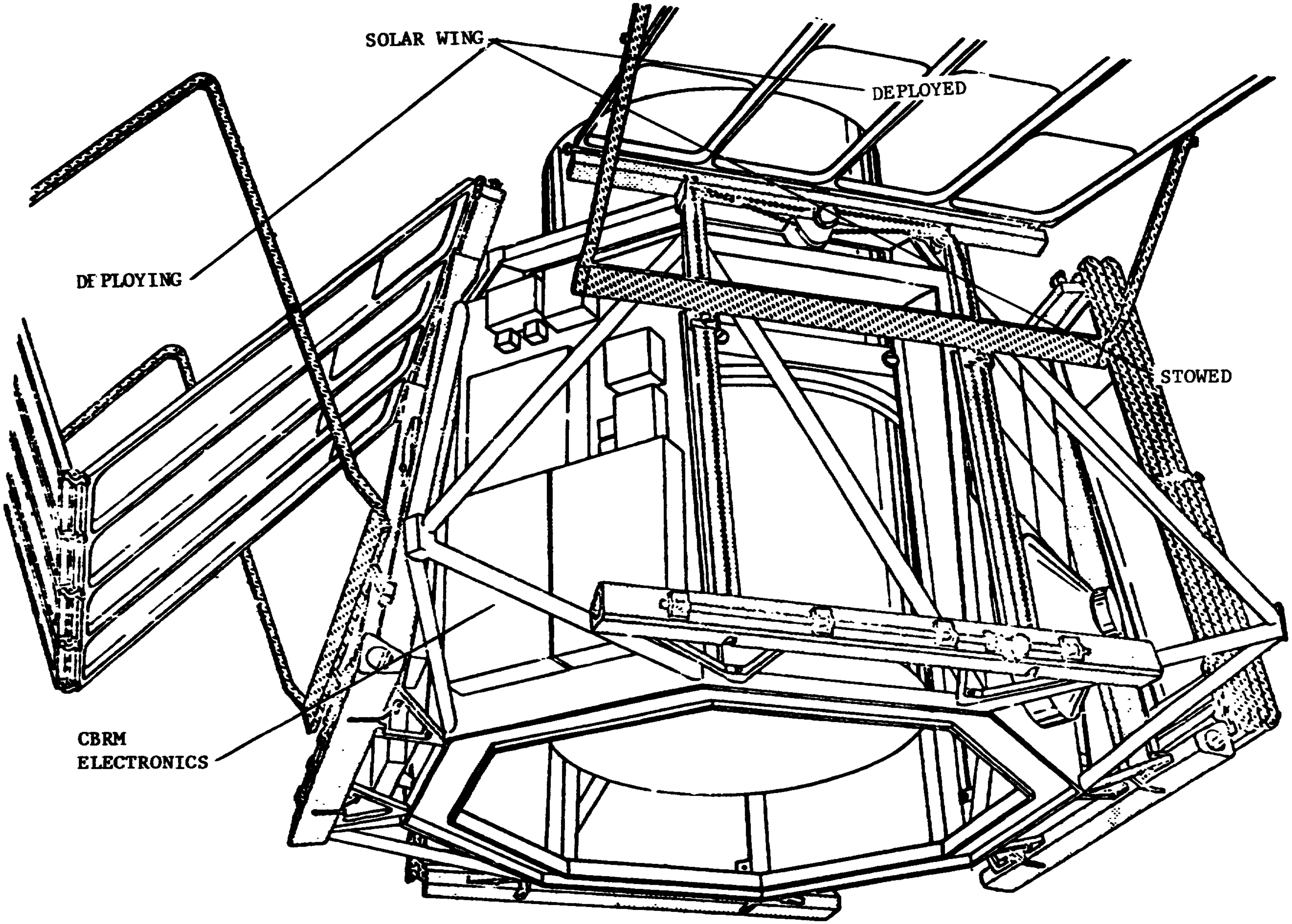


Figure 5.8b ATM Equipment Locations

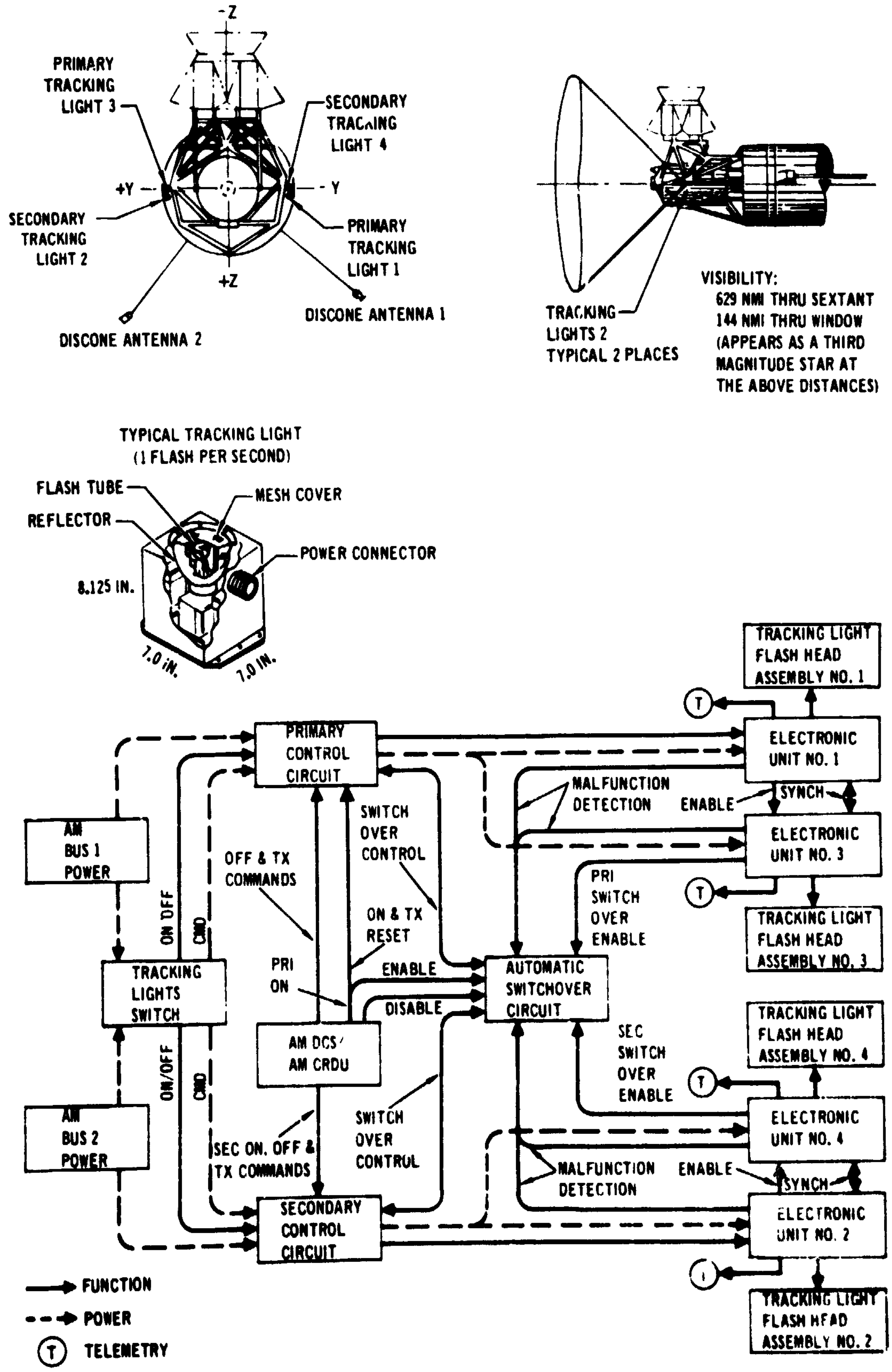


Figure 5.9a Tracking Lights

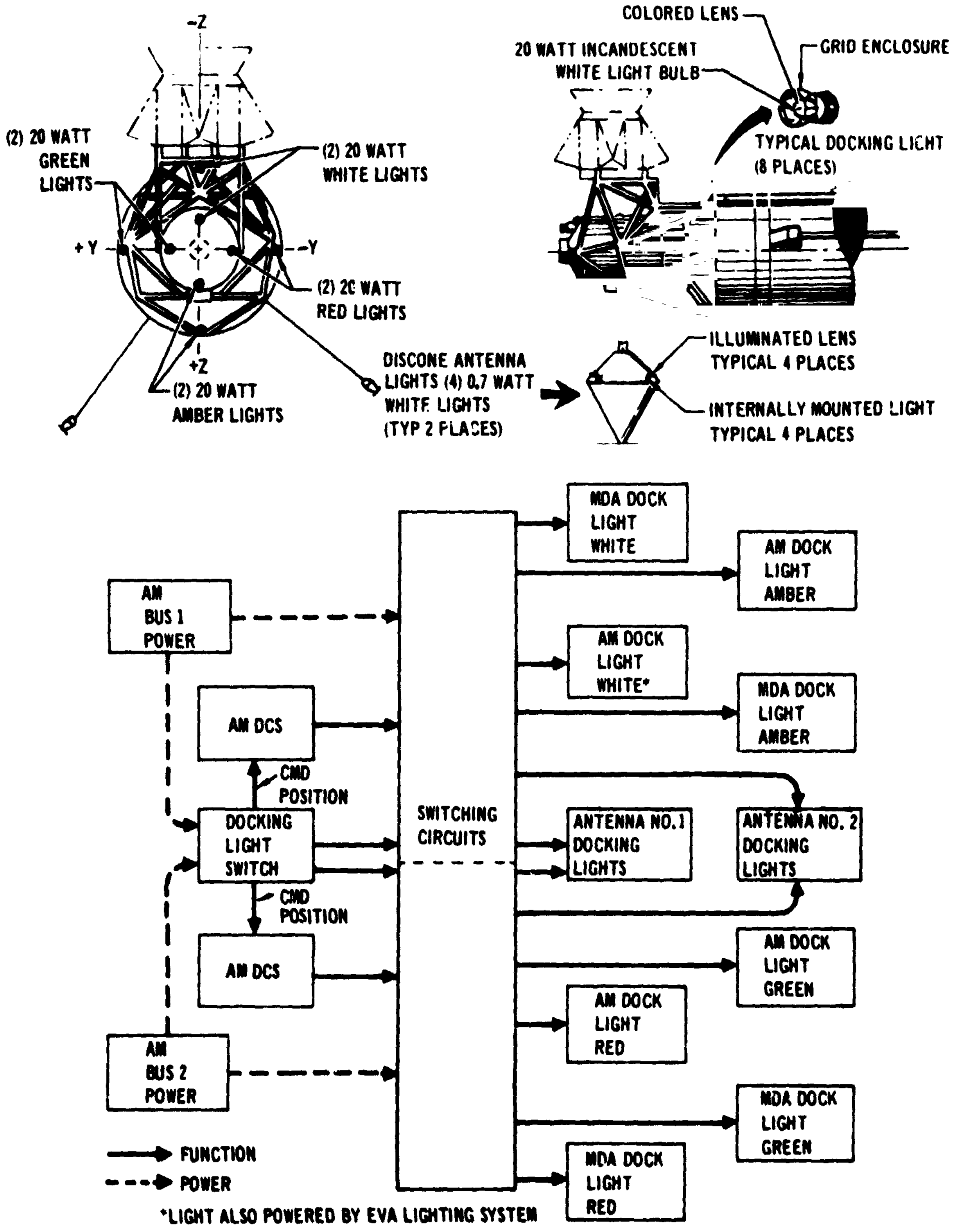


Figure 5.9b Docking Lights

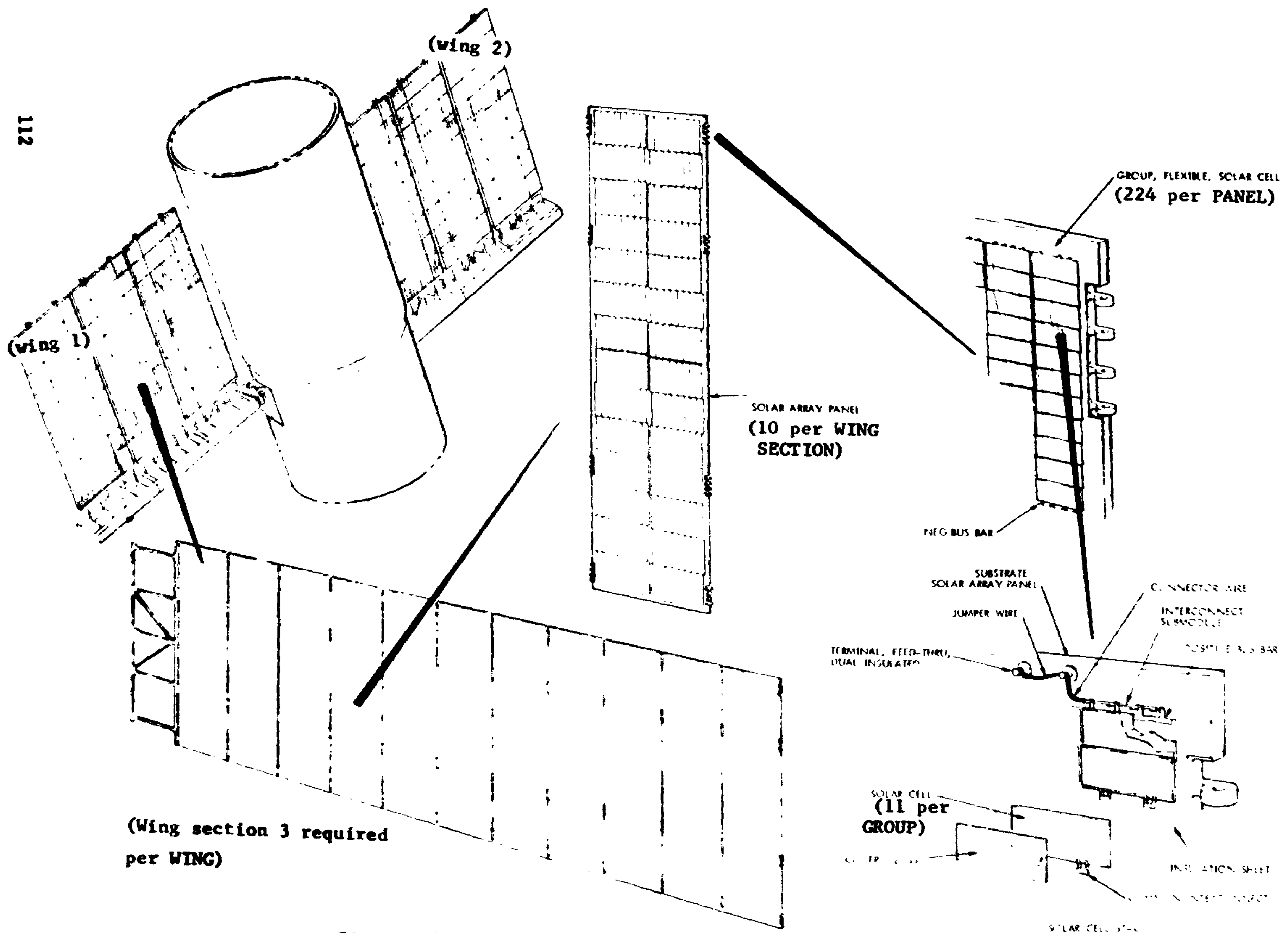


Figure 5.10a OWS Solar Array Assembly Details and Description

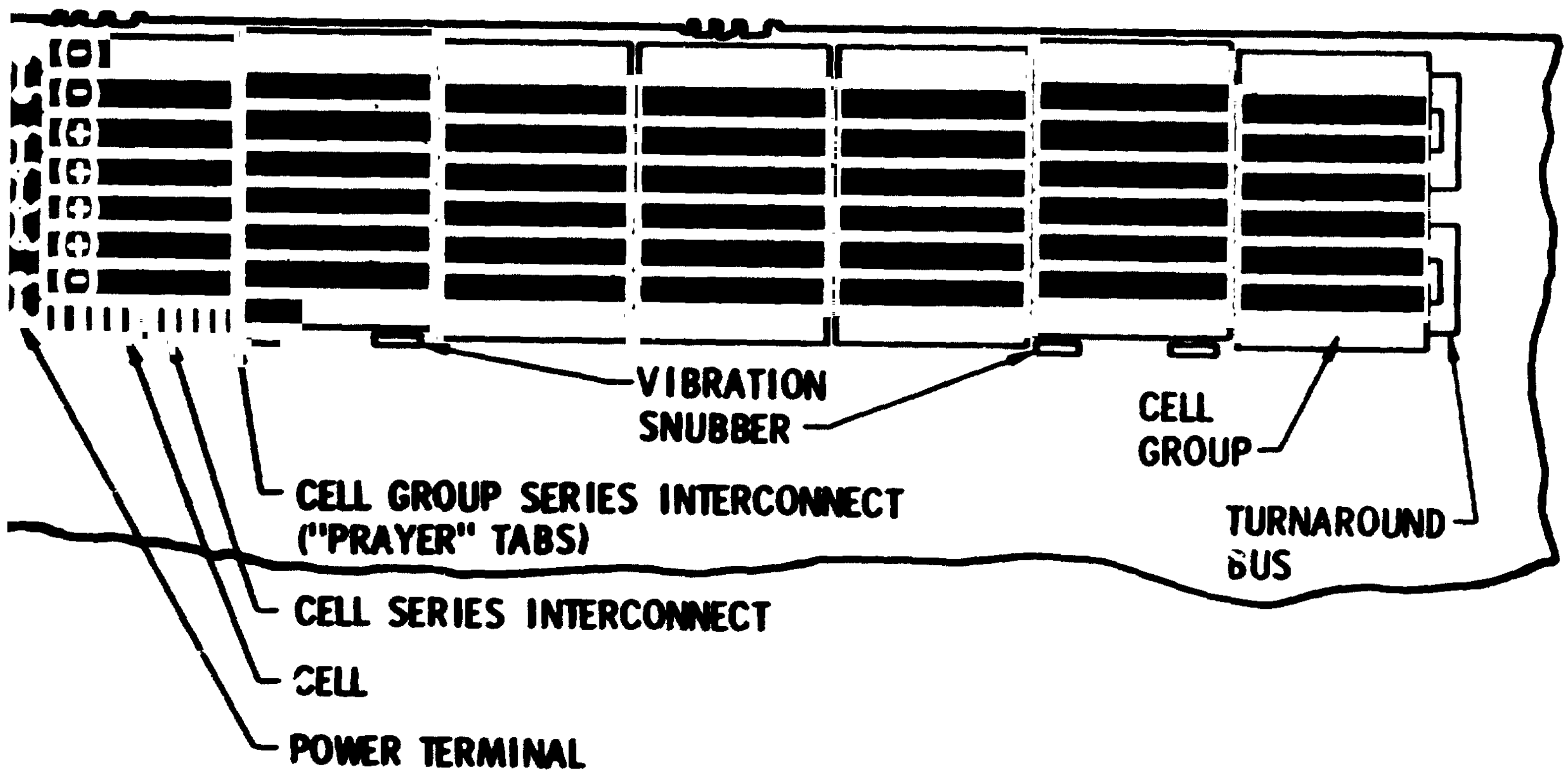


Figure 5.10b OWS Solar Cell Module Layout

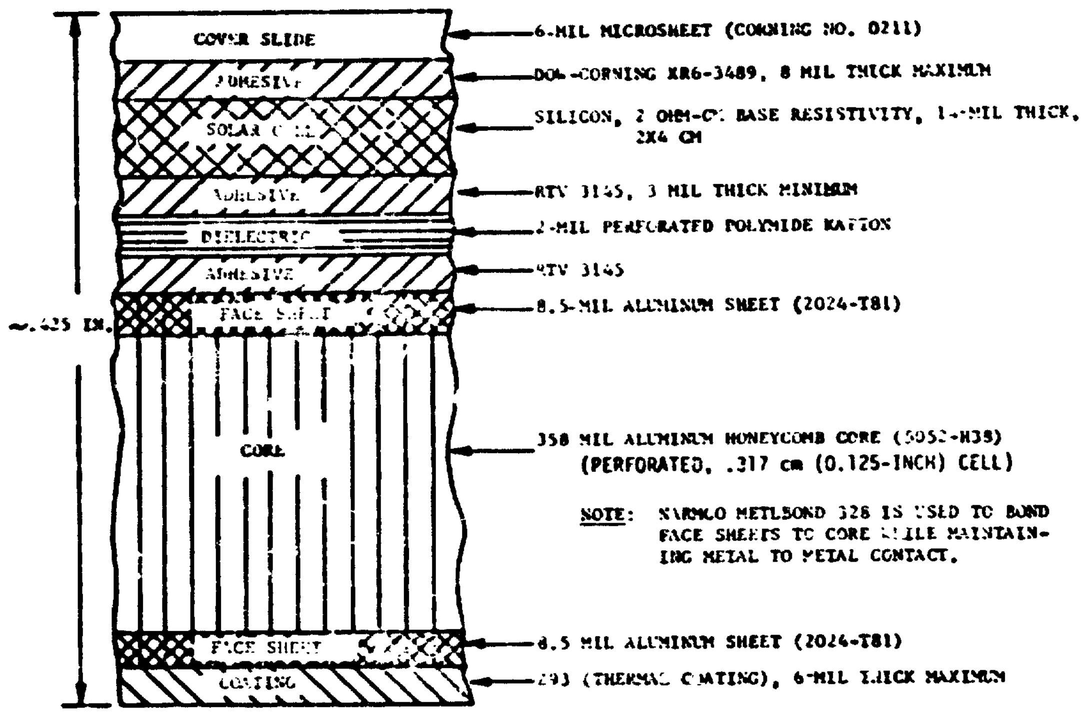


Figure 5.11 Cross Sections of OWS Solar Cell Module

PARAMETER	VALUE
ARRAY	
SIZE	- 9.4 m^2 (372 inches long, 328 inches wide) (per wing)
WEIGHT	- 1840 kg (4,056 pounds) (including deployment and stowage structures)
PANELS	- 30 per wing
MODULES	- 240 total
SOLAR CELLS	- 147,840 total
SOLAR PANEL	
SIZE	- 6.5 m (27.13 inches wide), 3 m (120.70 inches long)
WEIGHT	- 28 pounds
MODULES	- 4 per panel
SERIES CELLS	- 154 per module
PARALLEL SERIES STRINGS	- 4 per module
TOTAL CELLS	- 2,464 each
SUBSTRATE	- Aluminum Facesheet/Aluminum Honeycomb
DIELECTRIC INSULATION	- Perforated 0.002-inch Kapton
SOLAR CELL GROUP	
TYPE	- Overlapped
CELLS PER GROUP	- 11 series
CELL INTERCONNECTOR	- .025 mm (0.001 inch Kovar) (Solder Plated)
GROUP INTERCONNECTOR	- .075 mm (0.003 inch Kovar) (Solder Plated)
CELL TO SUBSTRATE ADHESIVE	- RTV 3145
SOLAR CELL	
TYPE	- N/P
SIZE	- 2x4 cm (0.014 inch thick)
EFFICIENCY	- AMO, 28°C-11.1 percent Average Bare, New
BASE RESISTIVITY	- 2 ohm-cm
CELL CONTACT	- AgTi Machine-Pressed Fully Solder Covered Contacts

Table 5.I Physical Characteristics of OWS Solar Array

(4) strings indicated were connected electrically in parallel at the module output terminals.

The electrical power was routed from each solar cell module through stabilizer beam channels on the backside of each wing section, inside the beam fairing, and then into the forward skirt of the OWS. Inside the forward skirt, solar module power entered the Power Unit which provided diode isolation and busing into eight (8) groups of 15 modules each. Power was then routed from the Power Unit to the AM/OWS interface. The eight (8) 15 module groups from each wing were paired to make eight (8) Solar Array Groups (SAGs) of 30 modules each. Each of the eight (8) groups in turn was connected to one of the AM Power Conditioning Groups (PCGs) to form the AM/OWS Electrical Power System. The AM included provisions for applying the output of each SAG to an alternate PCG. Figure 5.12 illustrates a typical SAG/PCG interface.

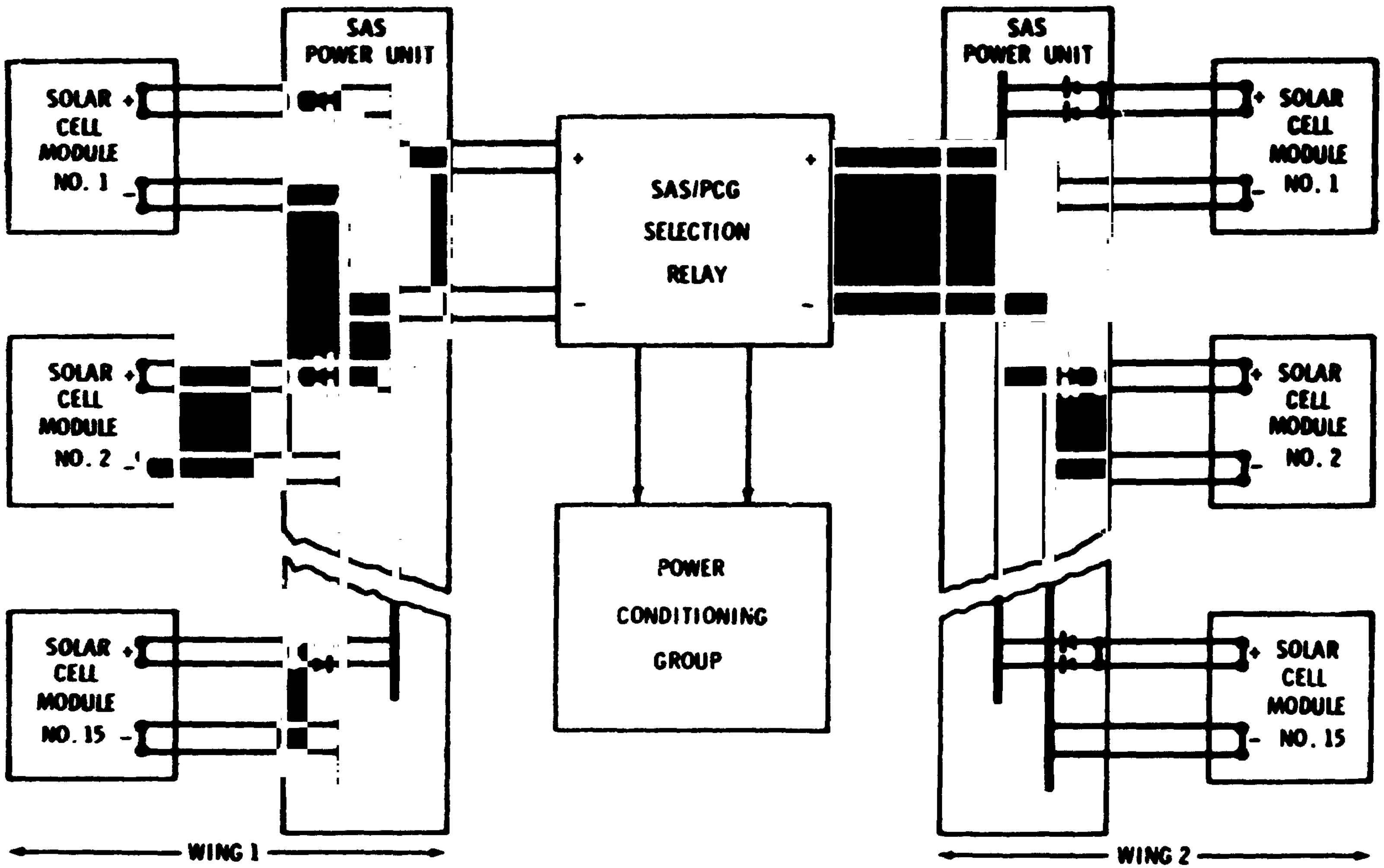
Solar array temperature was determined by 20 temperature transducers, ten (10) on each wing. Transducer locations were defined based upon predicted temperature profiles for each wing.

SAS deployment occurred in two phases, beam fairing deployment, and wing section deployment. Each phase utilized redundant (primary and backup) exploding bridgewire (EBW) firing systems consisting of EBW detonators and EBW firing units.

The firing unit (FU) for the primary system received commands from the Instrument Unit (IU) through the OWS switch selector. After the AM deploy buses were commanded On through the IU automatic sequence, the deployment sequence was initiated by the IU automatic sequenced command SAS Fairing EBW FU No. 2 CHARGE. This command applied 28 Vdc Deploy Bus 2 power to charge EBW FU 2. Five seconds later, the SAS Fairing EBW FU No. 2 FIRE command was sent, triggering FU 2 and detonating the CDF of the primary ordnance system.

Beam fairing fully deployed indications performed a switch interlock function preventing the wing sections from being deployed prior to beam fairing full deployment. Commands to deploy wing sections were enabled by these switches. The same switches were also interlocked with the automatically sequenced IU commands to deploy the OWS Meteoroid Shield.

Wing Section deployment was to be initiated upon completion of beam fairing deployment. SAS Wing Section EBW FU No. 2 CHARGE was sent by the IU. The command closed relay contacts that apply DEPLOY BUS 2 POWER to charge the EBW FU 2. Five seconds later, provided the fairing deployment interlock was closed, the trigger command, SAS Wing Sections EBW FU No. 2 FIRE was issued. This detonated the SAS wing section deployment ordnance.



NOTE: FIFTEEN (15) SOLAR CELL MODULES FROM EACH WING ARE COLLECTED FOR A TOTAL OF 30 MODULES PER POWER GROUP. THIS ARRANGEMENT IS TYPICAL FOR EACH OF THE EIGHT POWER GROUPS

Figure 5.12 Solar Array/Power Conditioning Group Interface

Beam fairing and wing section deployment backup commands were transmitted by way of the AM Digital Command System (DCS). The backup deployment system which were independent of the beam fairing deployed interlock switches, and were powered from DEPLOY BUS 1.

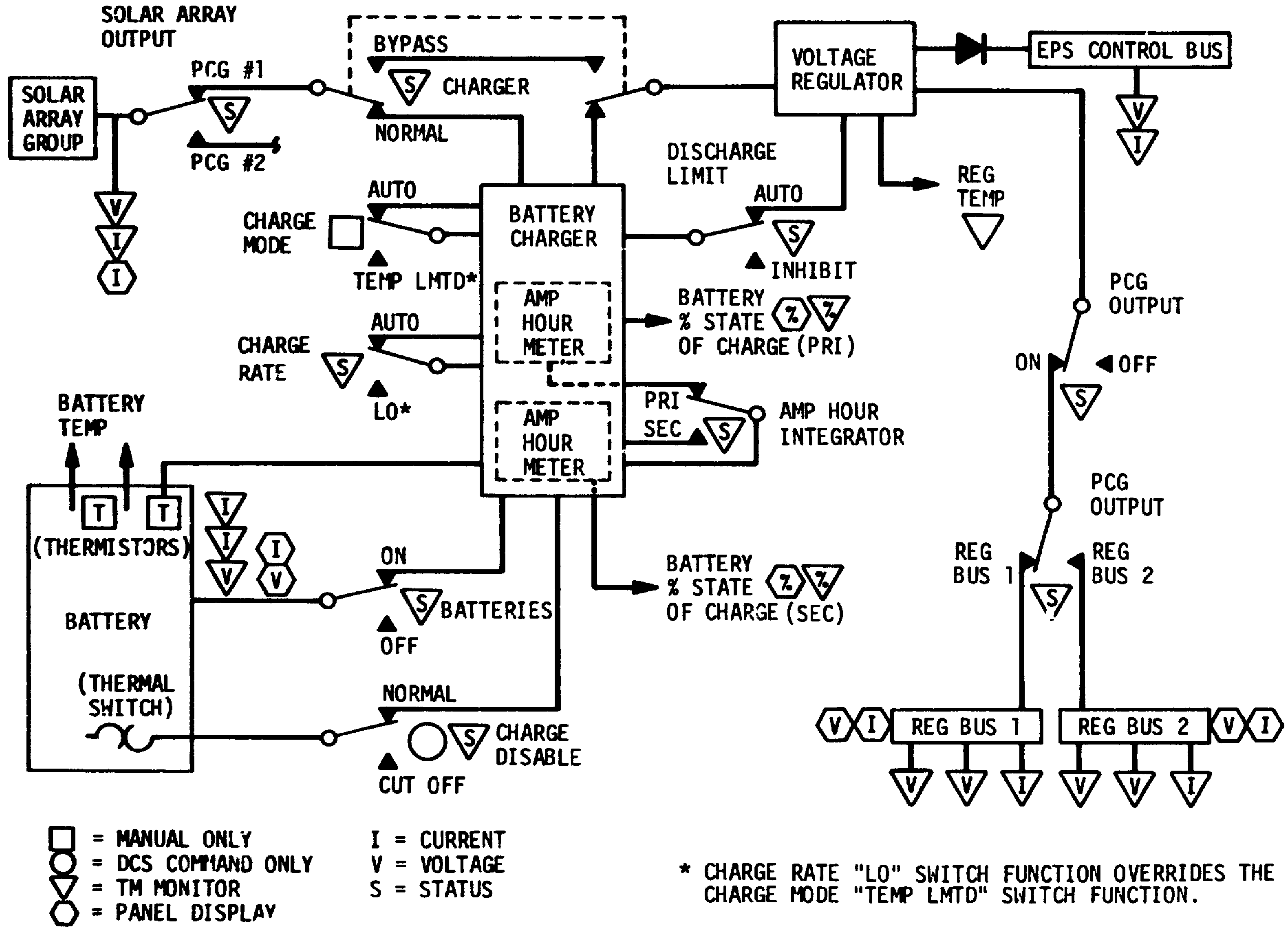
(b) Power Conditioning Groups. A total of eight power conditioning groups were required to efficiently utilize the total energy received from the solar array. The number of PCGs also provided redundancy to meet mission reliability requirements. A typical PCG circuit configuration, including controls and instrumentation, is shown in Figure 5.13. The control functions are discussed as they relate to the operation of the major PCG components; the battery, battery charger, and voltage regulator. The PCG equipments interfacing with the OWS solar array were designed to operate compatibly with the solar array group design characteristics. The following paragraphs describes the characteristics of major items of hardware as shown in Figure 5.14.

1 Battery Charger. A reference summary of the physical and performance characteristics of a battery charger is given in Table 5.II and Figure 5.15. Each battery charger conditioned the power obtained from an associated solar array group, controlled the charging of its associated nickel-cadmium battery, and fed solar array conditioned power or battery power to its associated voltage regulator to satisfy system load requirements. The battery charger was designed to condition a maximum instantaneous and a maximum continuous output power of 2300 and 1500 watts, respectively.

The acceptable AM/OWS interface voltage range for battery charger operation was from 125 volts maximum at open circuit to 51 volts minimum at the peak power point of the solar array group V-I characteristics.

The battery charger consisted functionally of three major circuits; the switching regulator circiut, the peak power tracker circuit, and the ampere-hour meter circuit. The switching regulator was the actual power conversion circuit which conditioned the solar array power and provided the regulated output. The peak power tracker restricted the load demand on the solar array group to the peak power available from the group. The ampere-hour meter controlled the charging modes for the battery.

Peak Power Tracker - The function of the peak power tracker circuit was to automatically adjust the battery charger output voltage such that the power demand on the associated solar array group was limited to its available peak power. Without the peak power tracker, a load demand in excess of the available peak power would cause a sharp drop in the solar array output voltage and, therefore, a sharp drop in its output power. Under limiting conditions, it caused operation at or within 5% of the solar array peak power point. Redundant, active,



* CHARGE RATE "LO" SWITCH FUNCTION OVERRIDES THE CHARGE MODE "TEMP LMTD" SWITCH FUNCTION.

Figure 5.13 Typical PCG Circuit-Controls and Instrumentation

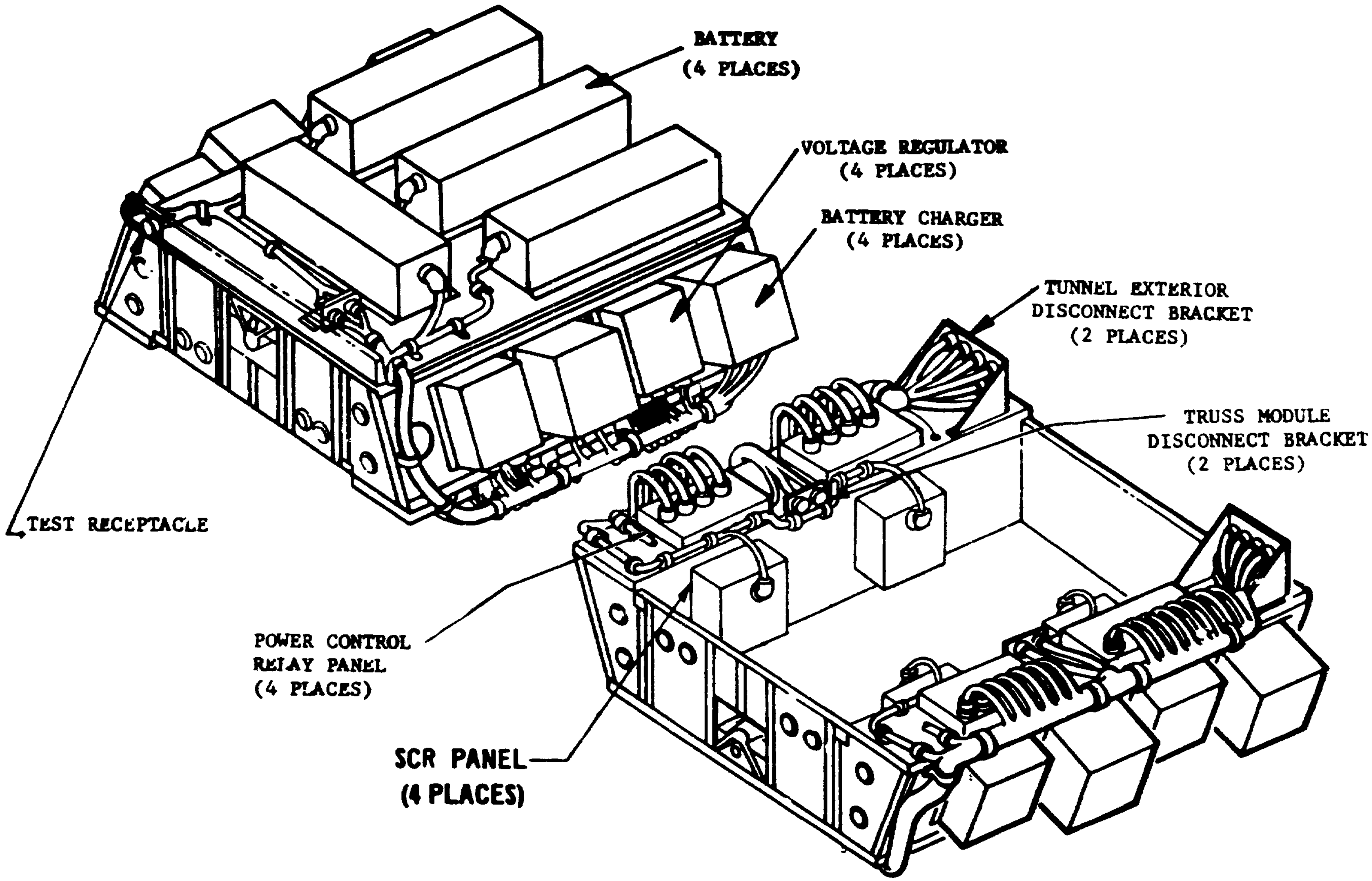


Figure 5.14 PCG Componen' Locations

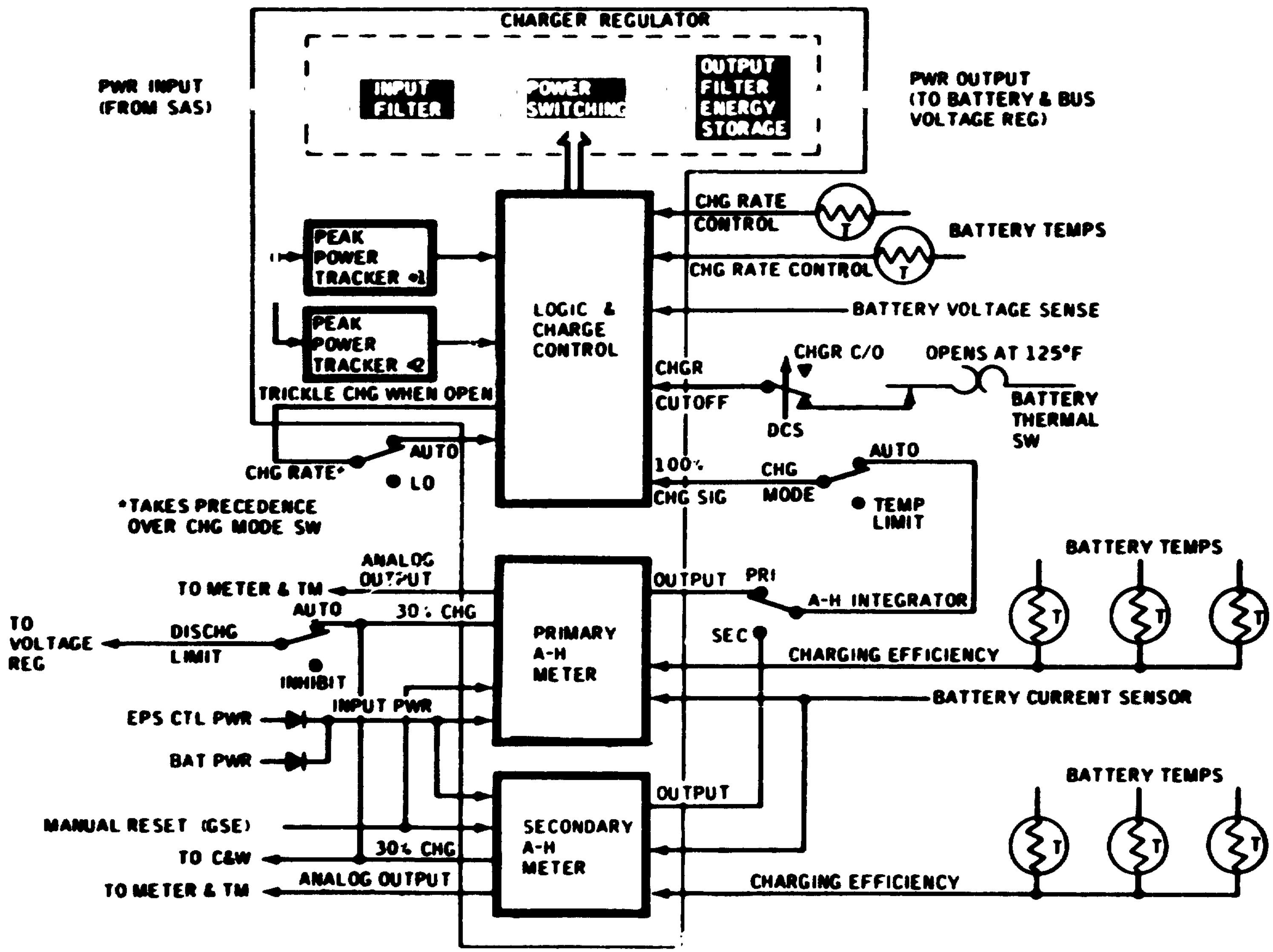


Figure 5.15 Battery Charger Functional Diagram

PHYSICAL CHARACTERISTICS

Size: Maximum Envelope Dimensions, 7.25"x10"x11.55".
Weight: 27 lbs (maximum)
Connectors:
Cooling: Coldplate mounting provides active cooling

PERFORMANCE CHARACTERISTICS

Input Characteristics

Maximum Voltage: 125VDC
Turn On Voltage: ≈64 VDC
Turn Off Voltage: ≈51 VDC at AM/OWS Interface
Maximum Power: 2580 watts

Output Characteristics

Maximum Voltage: 53 VDC
Voltage Control Signals: Battery Temperature, Battery SOC, Load Demand, and Manual and DCS Control Commands.
Maximum Instantaneous Power: 2300 watts
Maximum Continuous Power: 1500 watts

Battery Charger Losses

Losses do not exceed the following:

	Battery Supplying Total Power	Array Supplying Total Power
No Load Losses*	1.7 watts	23 watts (maximum)
Full Load Losses*	1.7 watts	212 watts (maximum)

* Ampere Hour Meter losses are not included but they shall not exceed 3.4 watts total.

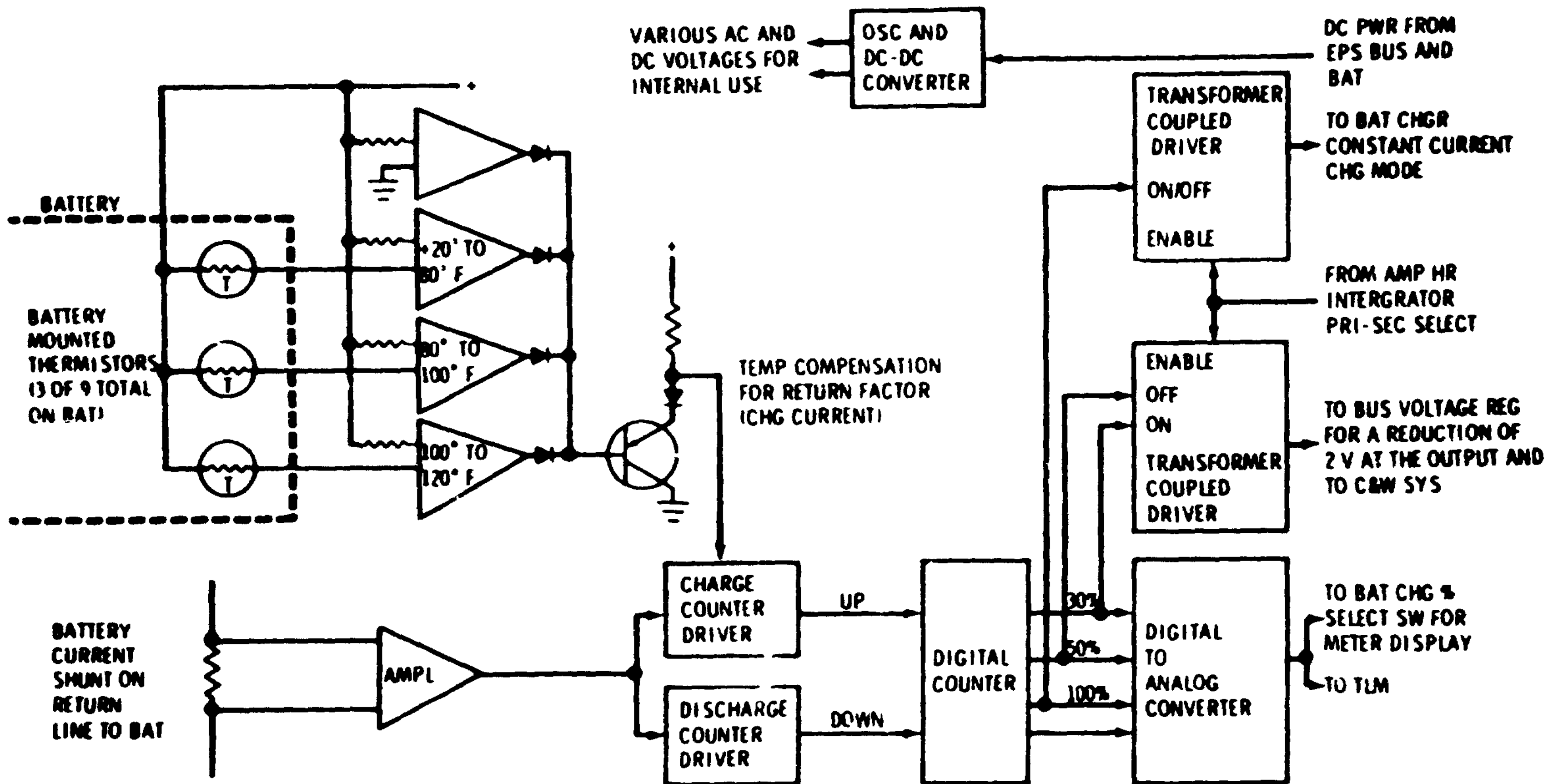
Table 5.II Battery Charger Physical and Performance Characteristics Summary

peak power tracker circuits were provided in each battery charger for improved system reliability.

In addition, the peak power tracker circuit was designed such that any failure within the circuits affected only its peak power tracking function and did not affect any other function of the battery charger.

Ampere-Hour Meter - The function of the ampere-hour meter circuit was to continuously compute the state-of-charge (SOC) of the associated battery and to provide charge control signals based on the computed SOC. This was accomplished by monitoring the battery discharge in ampere-hours during dark periods and the battery recharge in ampere-hours (including the return factor) during daylight periods. The battery status at any time was then computed in % SOC based on starting at 100% with a fully charged battery. The 100% SOC was based on a battery capacity of 33 ampere-hours. The primary control signal, generated when the computed SOC reached 100%, terminated the voltage limited charge mode and initiated the current limited charge mode. An analog signal indicating the computed SOC was also generated in the ampere-hour meter for telemetry and display usage. Two identical ampere-hour meter circuits were provided in each battery charger, as shown in Figure 5.16. Both of these circuits computed the battery SOC at all times and provided a continuous analog signal indicating computed battery SOC for telemetry and display. However, only one of these circuits provided battery charge control signals at any one time. Selection of either the primary or secondary circuit for control purposes was made by a DCS command or by a crew manual switch.

The current flowing from the battery during discharge cycles and to the battery during charge cycles was integrated with respect to time by the ampere-hour meter to determine changes in the battery state-of-charge. Temperature compensation was provided during charge cycles to account for the inter-relationship between charging efficiency and battery temperature. Three thermistors in the associated battery provided temperature sense signals to the compensating network of the ampere-hour meter. The ampere-hour meter then varied the ratio of the ampere hours delivered to the battery during charge to the ampere hours removed from the battery during discharge based on battery temperature during charging. The "return factor" was automatically varied as the battery temperature changed. The battery was considered fully recharged when the ampere hours delivered to the battery were equal to the ampere hours removed multiplied by the "return factor." At that point, the ampere-hour meter output indicated a battery SOC of 100%. During system operation, the battery was alternately charged and discharged. Since it was not necessarily completely discharged or fully recharged during any one charge/discharge cycle, the ampere-hour meter was designed to be capable of reversing its mode of measurement any number of times without losing its memory of the battery SOC. The ampere-hour meter provided several



(Two Identical Units Required per PCG)

Figure 5.16 Ampere-Hour Integrator Functional Diagram control signals which were generated by specific SOC values. When the ampere-hour meter computed that the battery was fully charged or at the 100% SOC value, a signal was provided to the battery charger regulator circuit to cause operation in the constant current battery charging mode rather than the voltage limited battery charging mode used at computed SOC values less than 100%. When the computed battery SOC value dropped to 30%, a signal was provided to the associated voltage regulator which caused the voltage regulator to reduce its output voltage by approximately two volts. This effectively removed all load from the PCG and permitted all available power from the associated solar array group to be utilized for the recharging of the battery. The initiating control signal could be inhibited by a DCS command or by astronaut control. Subsequent recovery of the computed battery SOC to 50% automatically removed this control signal and allowed the voltage regulator to return to its original voltage level of operation. Each ampere-hour meter circuit provided a 0 to 5 volt signal equivalent to a computed 0 to 100% battery SOC. One dual meter was provided on the instrument panel to display computed battery SOCs. The crew manually selected one of the eight sets of ampere-hour meter circuit signals (primary and secondary) to be displayed on this meter. This was accomplished by means of an eight position, panel mounted, rotary switch. All eight sets of computed SOC signals were continuously available for telemetry usage.

Hardline controls were provided to permit setting each ampere-hour meter circuit to a 100% SOC value at any time during ground operations and particularly prior to launch. Interruption of power and the subsequent reapplication of power to the ampere-hour meter circuits in a battery charger, reset the bidirectional counter circuits, their memory was lost, and the SOC value went to 0%. Power was provided to the ampere-hour meter circuits of each battery charger from two sources, the associated battery and the EPS control bus. To remove power, it was necessary to intentionally open both the associated "Ampere Hour Integrator" and "Battery Control" circuit breakers.

Regulator - The battery charger regulator was a pulse width modulated type voltage regulator where the regulated DC output voltage was less than the unregulated DC input voltage. The regulator consisted of an input filter and five individual power modules. A multiple number of regulator modules were used for both increased system reliability and for minimum parasitic losses at low load conditions resulting in overall high efficiency of operation.

The regulated DC output voltage of the battery charger was controlled by various signals generated within the PCG to be compatible with load, battery, and solar array requirements and characteristics. Conditions which affected the charger output voltage include: battery temperature, battery voltage, battery state-of-charge, solar array peak power, load power, and the status of applicable EPS control elements. The output voltage, depending on these conditions, varied from approximately 38.7 volts up to a maximum of 53 volts.

A battery charging cycle could include three modes of battery charger operation, a peak power tracking mode as explained above, a voltage limited mode and a constant current mode. A charging cycle would start with the battery SOC at some value less than 100% as computed by the AH meter. The battery charger would operate in the peak power tracking mode until the battery terminal voltage increased to the temperature dependent voltage limit. The battery charger would then operate in the voltage limited mode and provide an output voltage determined by the battery temperature. The voltage in this mode varied from nominal 42.8 volts to 48 volts. This voltage level provided for a high initial rate of battery charging. The 48 volts, possible in this mode, was the upper limit on the voltage applied to the battery under any circumstances.

When the battery SOC, as computed by the ampere-hour meter circuit, reached 100%, the ampere-hour meter circuit provided a control signal. In response to this signal, the battery charger switched from the voltage limited mode to the constant current mode. In this mode the current to the battery was sensed, and the regulator output voltage was adjusted to maintain the battery charging current at 0.75 ± 0.5 amps.

The battery charger would automatically modify the charging cycle described above if certain operating conditions were violated. If the battery terminal voltage dropped below 25 volts during voltage limited mode charging, the battery charger would change to the constant current mode. Battery charging in either mode was terminated, and battery current was reduced to zero amps if the battery temperature exceeded a high temperature limit of approximately 120°F as measured by thermistors in the battery. A thermal switch in the battery acted as a backup to the thermistors and provided the same results at a maximum temperature of 125°F.

Several manual and DCS controls could be used to modify the charging cycle. The Charge Mode Control (manual only) when set to its temperature limited position inhibited the 100% SOC signal. This prevented the automatic changeover from the voltage limited mode to the constant current mode when 100% SOC was reached. Battery charging would then proceed in the voltage limited mode as long as the battery temperature limit was not reached. The Charge Rate Control (manual or DCS) when set to its low position restricted charging to the constant current mode. This included overriding of the Charge Mode control. The Charge Disable control (DCS only) when set to its cutoff position caused the battery charger to maintain the battery charging current at zero amperes. The positive power connection from the battery to the battery charger could be opened by positioning the battery switch (manual or DCS) to its off position. This condition was sensed by the battery charger as a complete loss of the battery voltage signal. The battery charger voltage, then applied only to the voltage regulator, was controlled at 52 $\pm$ 1 volts for this condition.

The peak power tracker circuit of the battery charger, as previously described, limited the load on the solar array to the peak power available. The peak power tracker, in effect, controlled the battery charger regulator to adjust its output voltage until the output power corresponded to the peak power point value of the solar array. This reduction in voltage did not effect the power supplied to the system load because of the characteristics of the PCG voltage regulator. It did, however, reduce the charging current to the battery and thereby reduced the total power output from the battery charger to the value allowed by the available solar array input power.

There were four different operational conditions arising from varying levels of available solar array power. The condition where solar array power was sufficient to supply both the equipment load and the battery load has previously been described. Under the condition where the available power was sufficient to supply equipment loads, the charger output voltage was reduced such that the equipment load was satisfied and the remaining available power was utilized for charging the battery. When the available array power was not sufficient to supply the equipment load alone, the charger output voltage was reduced further until the battery and battery charger in parallel could supply the equipment load. When the solar array voltage became less than approximately 51 volts at the AM/OWS interface, the battery charger was switched off and equipment loads were totally supplied from the battery. The latter condition included the normal operation during orbital dark periods.

2 Battery. The batteries were nickel-cadmium batteries designed for active cooling. A reference summary of battery physical and performance characteristics is given in Table 5-III and Figure 5.17.

The function of the batteries was to furnish power to equipment loads through the AM EPS voltage regulators during orbital dark periods when there was no solar array power available.

The batteries were recharged whenever array power greater than the bus load requirement was available. The charge potential applied to the battery during the initial phase of recharging was limited to a level consistent with maintaining peak solar array power utilization. This limitation was a function of the peak power circuitry within the charger. The recharge potential necessary to maintain peak solar array power utilization increased as the batteries approached completion of

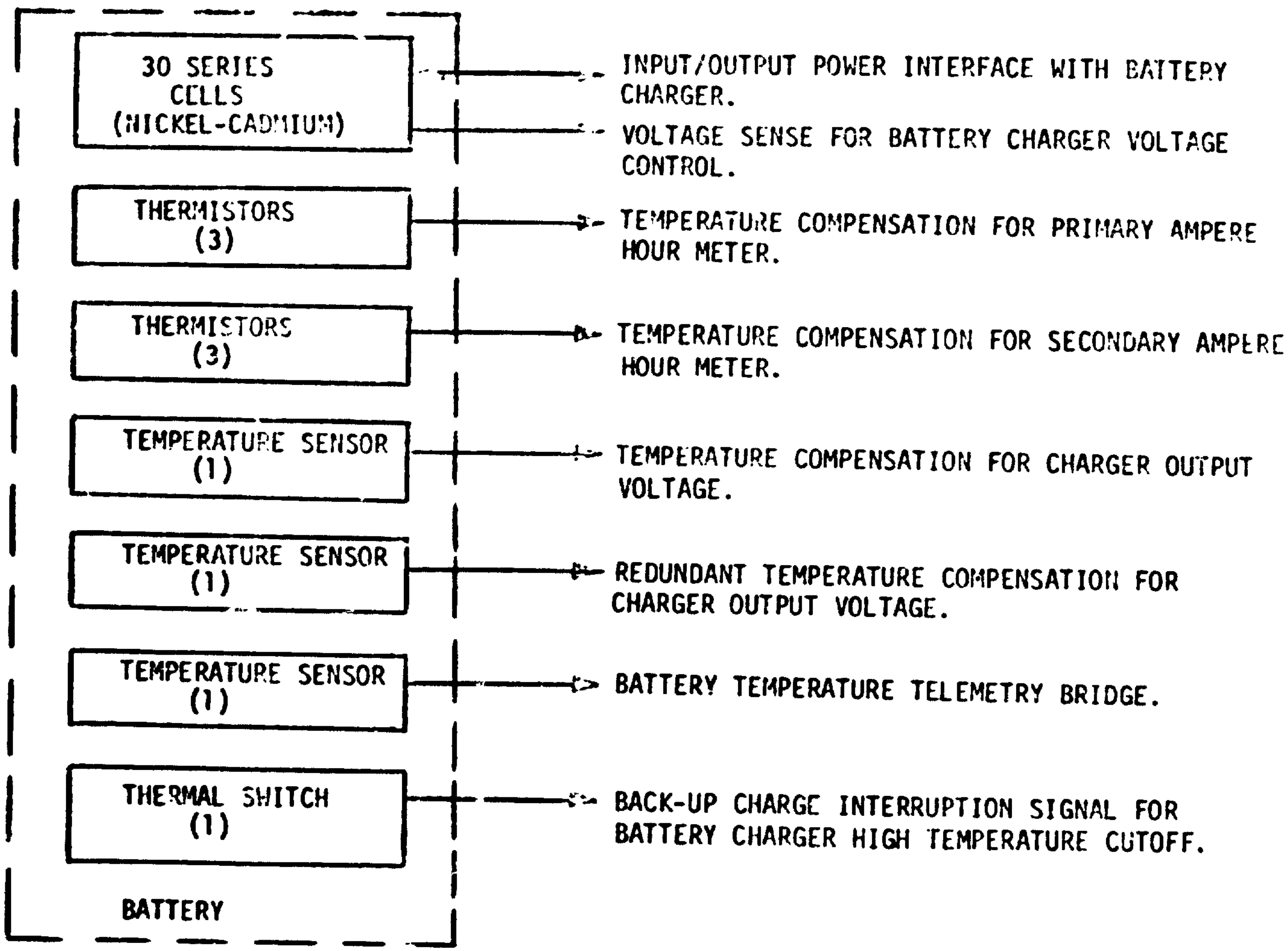


Figure .17 Battery Output Functional Diagram

PHYSICAL CHARACTERISTICS

Size: Maximum Envelope Dimensions, 7" x 8.25" x 27.25"
Container Material: Cast Aluminum
Power and Instr Connector: Mates with PT06P-22-41P.
Cell Monitor Connector: Mates with PT06P-18-32P.
Weight: 123 lbs Maximum
0.010 TIR on Bottom Surface for Coldplate Mounting.
Container Provided with Reseatable Relief Valve.
Number of Cells: 30 (each with reseatable relief valve).

PERFORMANCE CHARACTERISTICS

Ampere-Hour Capacity: 33 Ampere-Hours (Minimum Required)
(Based on 120°F operation and discharged at 18 ampere rate to a 30 volt terminal value).
Acceptance Ampere-Hour
Capacity Range on Flight Units: 40.5 to 42.9 Ampere-Hours
(Obtained at 75 ± 5°F and discharged at 18 ampere rate to a 30 volt terminal value).
Charge Voltage Range: 39.0 to 48.0 volts
Average Discharge Voltage: 36 volts
Container Relief Valve Operation: 35 ± 5 psia
Cell Relief Valve Operation: 200 ± 25 psia

Table 5.III Nickel Cadmium Battery Physical and Performance Characteristics Summary

recharge. This phase of recharge was terminated when a potential limit consistent with battery temperature was imposed by additional circuitry within the charger. Full utilization of the array power was no longer accomplished during the constant potential charge mode which continued until such time as the ampere-hour meter within the charger indicated sufficient recharge had been accomplished. Upon generation of such an indication the charger switched to a low level (0.75 $\pm$ 0.5 ampere) constant current charge mode for the remainder of the charging period.

Each of the eight batteries consisted of 30 series connected cells and associated temperature sensing devices packaged in an aluminum container.

Each cell consisted of a parallel connected group of positive and negative plates packaged in a stainless steel can and sealed with a cell header assembly. All plates were fabricated using a nickel wire sintered-nickel structure into which either active nickel or cadmium material was impregnated to produce a positive or a negative plate, respectively. Each plate had welded to it an annealed nickel tab to be used for the electrical attachment to the appropriate cell terminal. The header assembly contained the electrically insulated cell terminals and provisions for relief valve insertion. Seventeen nickel (+) plates and eighteen cadmium (-) plates, alternately arranged and separated by non-woven nylon, made up a cell pack. The cell pack was inserted into a deep drawn cell can once the plate tabs had been shaped and welded to the header assembly terminals, and the resultant pack had been wrapped in a nylon jacket. The header assembly was welded to the cell can to complete the cell assembly. Each cell was fitted with a self-reseating pressure relief valve; cell leakage criteria was the same as that imposed on hermitically sealed assemblies.

Each of the 30 cells was taped and then epoxy potted into one of the 30 individual compartments in the battery containers. Each battery also contained three platinum wire temperature sensors; two temperature sensor assemblies containing three thermistor elements, and a normally closed thermal switch. Figure 5.17 details the function of each of these units. The temperature sensing devices were placed such that the top of cell case temperature was monitored rather than terminal or cell interconnect temperatures to minimize or preclude terminal and/or cell interconnect I^2R heating effects. The container was compartmentized to provide heat transfer from five surfaces of each cell to the container coldplate mounting surface. One electrical connector was provided for power transfer and charge control circuits, and another for ground access to individual cell voltages. The battery container also contained a pressure relief valve.

3 Voltage Regulator. A reference summary of the physical and performance characteristics of the voltage regulator is given in Table 5-IV. Eight voltage regulators were included, one in each PCG. The function of the voltage regulator was to furnish regulated DC power, within specified voltage limits, to the Reg. and the EPS control buses.

Each voltage regulator received input power from one of four sources, the nickel-cadmium battery, the battery charger, the battery and battery charger operating in parallel, or the associated solar array group. The input voltage level varied according to the output characteristics of these sources. The battery supplied power within an approximate voltage range of 30 to 40 volts depending on battery SOC and battery temperature. For the parallel battery and battery charger operation, the voltage would vary from approximately 35 volts to 40 volts depending on the amount of sharing and on battery SOC. The above conditions are discussed in detail in the descriptions of the battery charger and battery. In a contingency mode of operation, power could be supplied directly from the solar array group output to the voltage regulator input by positioning the charger switch to its bypass position. For this case, the input voltage to the regulator would be approximately 51 volts minimum to 125 volts maximum.

The voltage regulator provided specified voltage levels at the AM Reg. bus for input voltages from 32 to 125 volts. For input voltages less than 32 volts, the regulator provided the specified bus voltage level or the input voltage level minus approximately two volts, whichever was lower.

Each voltage regulator basically consisted of five power modules and an input filter. The multiple number of power modules was included in the design for improved system reliability. Each power module was a pulse-width modulated type regulator, where the output voltage was less than the input voltage at all times. The power module was designed to provide operation at a high efficiency even at low load conditions.

A remote sensing signal for each regulator was obtained directly from the Reg. bus to which it was supplying power. Remote sensing eliminated the effects of variations in the line voltage drop between the regulator output and the Reg. bus. The voltage at any output current, as illustrated by the V-I curve, could be defined by the equation: $V_I = V_{OC} - I(V/A)$ where (V/A) is the slope factor determined by the regulator design. For the AM EPS voltage regulators, the slope factor had a value of 0.04 ± 0.002 volts per ampere.

The no-load voltage for each regulator was crew adjustable only by means of two EPS manual control potentiometers, a Reg. bus

PHYSICAL CHARACTERISTICS

Size: Maximum Envelope Dimension: 4.3" x 10" x 10.85"
Weight: 14 lbs (maximum)
Connectors:
Cooling: Coldplate mounting provides active cooling

PERFORMANCE CHARACTERISTICS

Input Voltage Range: Maximum: 125 VDC
Minimum: 1.0 volt above regulated output voltage
Conversion Efficiency: $\geq$93%
No Load Losses: $\leq$4.5 watts

Output Characteristics

Design for Parallel Operation
Open Circuit Voltage: 26 to 30 volts (By external Reg. Bus potentiometer adjustment)
Fine Adjust Voltage: $\pm$0.45 volts (Referenced to Reg. Bus adjustment setting)
Voltage Droop: -0.04 volts/amp at Reg. Bus
Regulated Voltage Accuracy: $\pm$0.05 VDC (Coldplate temperature range from +40°F to +120°F)
Regulation Current Range: 0 to 50 Amps
Maximum Current: 65 Amps
Short Circuit Current: 26 Amps

Table 5.IV Voltage Regulator Physical and Performance Characteristics Summary

and a fine adjust potentiometer. Each of these potentiometers was connected directly across the Reg. bus and furnished a signal to the voltage regulator from its adjustable contact.

There were two Reg. bus potentiometers, one for each of the two Reg. buses in the AM EPS. Each Reg. bus potentiometer was hard-wired to its Reg. bus, but its control signal was switched to each of the voltage regulators supplying power to that Reg. bus. It, therefore, simultaneously adjusted the outputs of a group of regulators in order to adjust the Reg. bus voltage level. The no-load adjustment voltage range provided by the Reg. bus potentiometers was from 26 to 30 volts.

There were eight Fine Adjust potentiometers in the AM EPS, one for each of the eight voltage regulators. The control signal output of each Fine Adjust potentiometer was hard-wired to an individual voltage regulator. The two sense leads of the potentiometer were automatically switched to whichever Reg. bus the regulator output is connected. The adjustment range associated with a Fine Adjust potentiometer was $\pm$ 0.45 volts with respect to the voltage level set by the appropriate Reg. bus potentiometer. The purpose of the Fine Adjust potentiometers was to provide an individual regulator adjustment to allow control of load sharing among regulators connected to a common Reg. bus.

In addition to the above parameters which affect the output V-I curve, the regulator output had an allowable drift of $\pm$ 0.05 volts under conditions of constant loading within the allowable output current range.

The output current range for voltage regulator specification performance was from 0 to 50 amperes. The voltage regulator automatically limited its output current to a maximum of 65 $\pm$ 3 amperes, regardless of loading conditions. For current loads in excess of 50 amperes the regulator was not required to maintain specified voltage performance. The regulator was, however, capable of operating continuously under any load condition without sustaining damage and was capable of providing specified performance upon removal of any excess current loading condition.

In a special mode of operation, the output of the voltage regulator was reduced by two volts upon receipt of a signal from its associated battery charger. This signal was the 30% battery SOC signal previously described in the battery charger description. The effect of the two volt reduction was to totally unload the regulator as previously discussed. Upon removal of the signal from the battery charger the voltage regulator output rose two volts to its original voltage level of operation.

(2) ATM.

(a) Solar Array. The solar array was stowed in a folded position and mechanically cinched to a supporting structure on the ATM (Figure 5.8). Table 5.V describes the physical characteristics of the deployment mechanisms. Deployment was to be accomplished automatically at approximately 25 minutes after liftoff. The solar array consisted of 18 solar array sources that comprised the four solar wings (see Figures 5.18 and 5.19). The Skylab cluster was to be normally oriented by the attitude and pointing control system such that the array would be held normal to the sunline during the orbital day. Each ATM solar array panel was composed of 20 solar cell modules that were arranged electrically in parallel. Each solar array source was electrically independent of the others and provided the power input to one CBRM.

The basic building block of the solar panel was the solar cell module. Two configurations of the module were used, and the physical description is detailed in Table 5.VI. A cross section of the solar cell is shown in Figure 5.20. The minimum power rating of a solar cell module under one solar constant (140 mW/cm^2), as specified for procurement, was 700 mA at 49 volts at 28°C. The power available from each solar cell module at other temperatures was inversely proportional to the operating temperature.

(b) CBRM. This power subsystem was modular in concept. It consisted of 18 solar panel sources and 18 Charger Battery Regulator Modules (CBRMs). A CBRM and a PCG perform essentially the same functions. Each CBRM was designed to operate at various power levels, as supplied by its associated solar cell panel, to condition, store, and control the power and provide power to the appropriate power buses. The maximum capability of each CBRM was 415 watts at an efficiency of 92 percent. The output of the CBRM was fed to two (redundant) buses. The 18 CBRMs were packaged as self-contained units. Each CBRM consisted of a battery charger, a rechargeable battery, and load regulator (see Figure 5.21). The CBRM also contained automatic protection and alert circuitry, telemetry and astronaut display circuits for monitoring, heater control circuits, and other automatic controls. Figure 5.22 is a simplified functional diagram of the CBRM circuits.

1 Charger. The battery charger had a step-down, single-ended switching regulator circuit designed to convert the wide range of input voltages from the solar array source to the level required for charging the battery, while achieving maximum utilization of solar array power. The solar array source fed the charger and regulator in parallel. The charger output was connected to the battery only when charging power was available. The regulator power demands were met first. The charger sensed the solar array source voltage

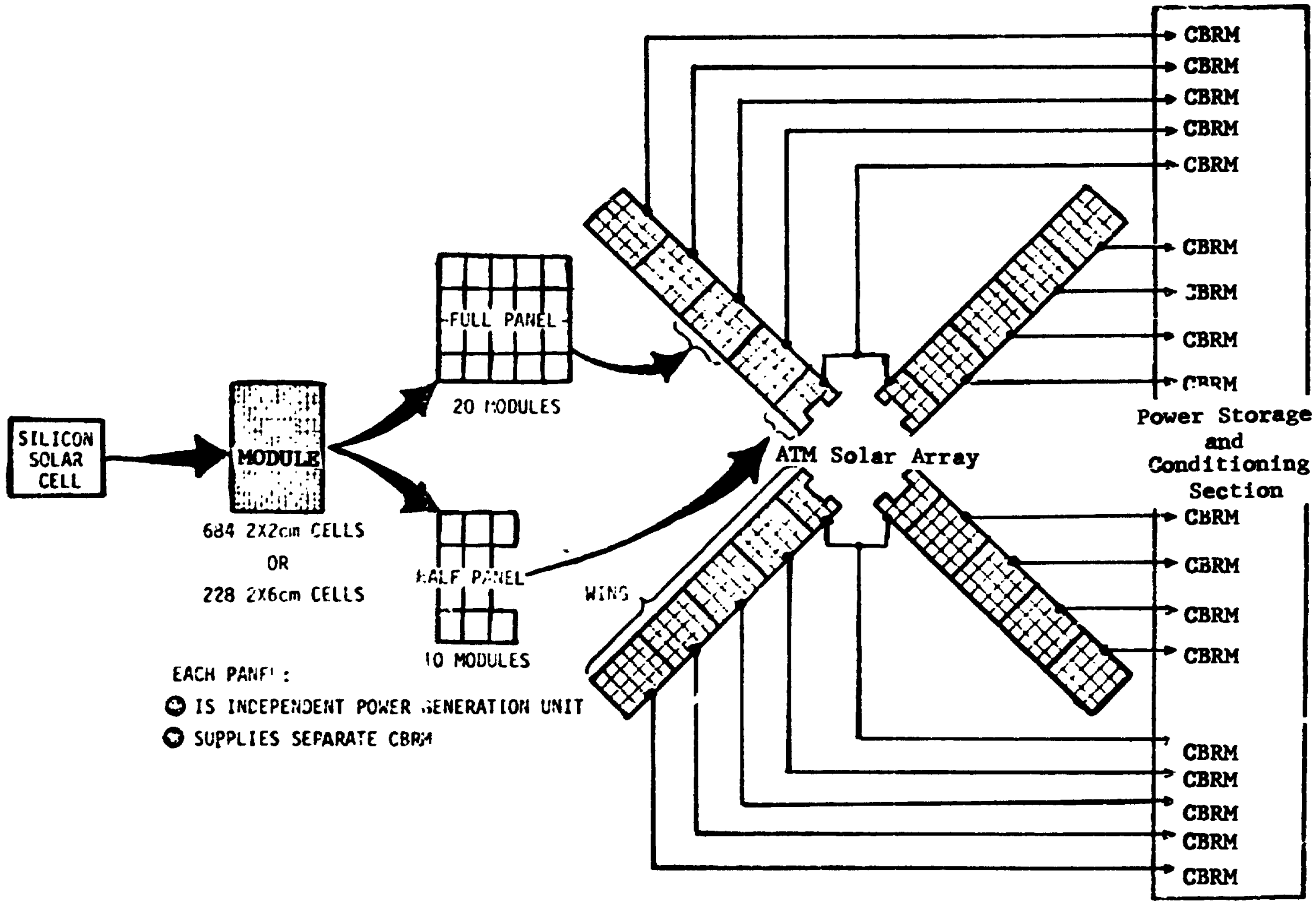


Figure 5.38 ATM Solar Array Assembly Details and Description

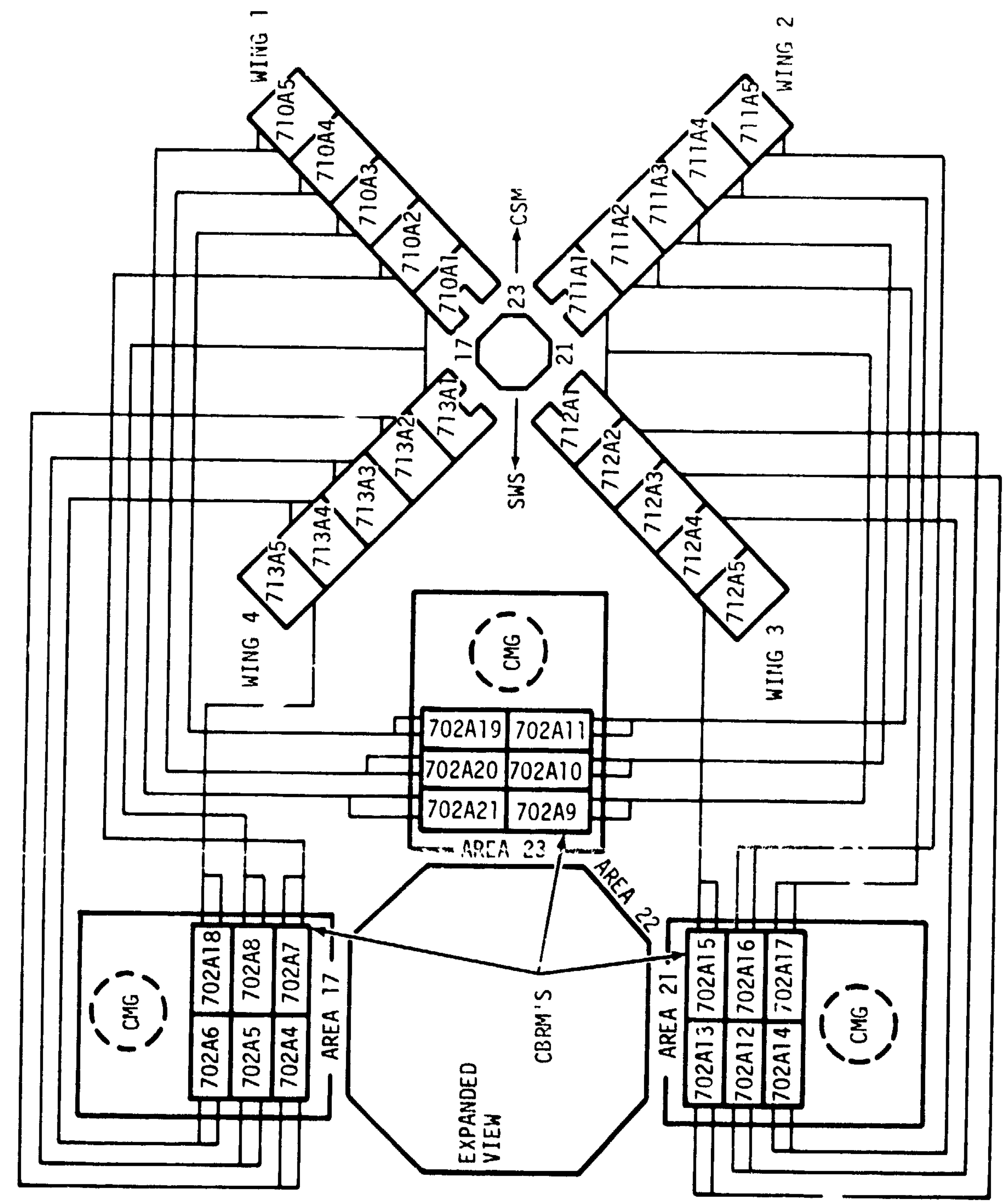
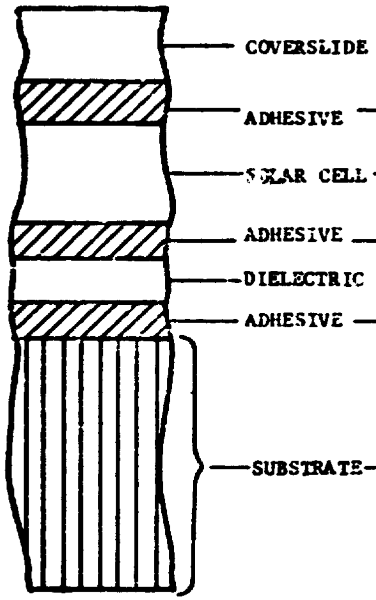


Figure 5.19 Solar Panel and CBRM Locations



CONFIGURATION 1	CONFIGURATION 2
12-MIL FUSED SILICA DOW CORNING 7940	
3-MIL DOW CORNING SYLGARD 182	
14-MIL, N/P SILICON, 2 X 2 cm	14-MIL, N/P SILICON 2 X 6 cm
5-MIL DOW CORNING SYLASTIC 140	
5-MIL MICA PLY (FIBERGLAS)	
5-MIL, EP 101	5-MIL, RTV 118
.025 mm (0.001-INCH) CORE, 49.7 kg/m^3 (3.1 LBS/FT^3), TOTAL THICKNESS INCLUDING FACE SHEETS 1.25 cm (0.5 INCH)	

Figure 5.20 Cross Section of ATM Solar Cell Modules

SUPPORT STRUCTURE - MAIN	
Construction	Stiff Frame, Box Beam (2 Vertical Track, 1 Upper and 1 Lower Box Beams With Stiffeners and Braces)
Material	Aluminum (6061-T6)
ATM/Wing Interface	6 Main Attachment Points Symmetrical About Wing Longitudinal Centerline
Dark End Attachment Points	2 Each Turnbuckle Fittings (With Spherical Bearings)
Sun End (Main) Attachment Points	2 Each Attachment Fittings (With Spherical Bearings)
SUPPORT STRUCTURE - PANELS	
Construction	Rectangular Frame - 5 Parallel Tubes, Interconnected at Ends by Hinge Fittings and Short Tube Sections
Material	1 in. x 2 in. Tubing, 0.06 in. Wall Thickness
Inboard Panel	Heat Treated Steel (4140)
All Other Panels	Extruded Aluminum (2219-T87)
PANEL/PANEL INTERFACE	
Hinge Fittings	5 Sets of Male/Female Clevises (Teflon Lined Spherical Bearings on Male Halves)
Shear Plates	5 Sets of Tapered Male and Female Plates - Mounted Adjacent to Hinges
DEPLOYMENT MECHANISM - WINGS	
Scissors Arms	5 Sets of Scissors Arms, End Attachment Hinges Incorporate Torsion Springs. Centers Incorporate Pivot (Flanged Journal Bearings) Points which Attach to Panel Outboard Centers.

Table 5.V ATM Solar Array Deployment Structural and Mechanical Components Physical Characteristics

<u>DEPLOYMENT MECHANISM - WINGS</u> (Continued)	
Material	1 in. by 2 in. Tubing 0.06 in. Wall Thickness (except Inboard Pair - 0.125 in.)
Inboard, Second and Third Pairs	Steel
Fourth and Fifth Pairs	Aluminum
All Hinge Fittings	Aluminum Castings (Precedent 71A-T6)
Scissors Arms Cross Beam	Aluminum (6061-T6) Beam Interconnect Between Inboard Scissors Ends and Track Beam Sliders
Electro/Mechanical Rotary Actuator	Dual Tandem Mounted, Metal Bellows Hermetically Sealed 28 VDC Torque Motors with Nutating Gears Driving a Dual Slip Clutch Output Ball Drive Cable Sheave
Ball/Drive Cable Slider	Dual Closed Loop 291 in. Long Cable/Slider. Nominal 0.125 in. Dia. Aircraft Cable with 0.312 in. Dia. Swaged Steel Balls Spaced 2.35 in. Apart and Secured via Turnbuckles at Both Ends to Track Beam Sliders
<u>CINCHING MECHANISM</u>	Retains Wing In a Rigid Package During Handling, Stowage and Launch
Cinching Ties	11 Each (7 Sun End, 4 Dark End) Ties Mounted on a Fifth Panel (Outboard) and Retained to Main Structure by Ball End Rod Seated in Torque Tube Rotary Ball Seat. Consists of Arm, Clevis, Turnbuckle Ball End Rod, Pivot Bolts and Torsion Springs
Pyrotechnic Thrusters/ Torque Tubes	2 Each Dual Piston and Cylinder Assembly Utilizing Two CDF 2000 Pyrotechnic Cartridges. Pistons are Secured to a Crank Which in Turn is Secured to the Torque Tubes

Table 5.V ATM Solar Array Deployment Structural and Mechanical Components Physical Characteristics (Continued)

DEPLOYMENT MECHANISM - WING ANTENNAS

Wing No. 1	Triangular Panel Assembly Hinge Mounted to Outboard End of 5th Panel. Deployed by Dead Position Torsion Springs, Retained by a Pretensioned Cable Activated Spring Plunger and Sear Pin
Wings No. 3 and 4	Dipole Antenna Assembly. Nestled in a Teflon Lined Cradle Which is Bolted to the Outboard End of the 5th Panel. Deployed by Torsion Springs, Retained by Cinching Strap and a Pretensioned Cable Activated Spring Loaded Plunger and Sear Pin

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Table 5.V ATM Solar Array Deployment Structural and Mechanical Components Physical Characteristics

PARAMETER	VALUE
ARRAY	
SIZE	- 13.2 m (521 inches long), 2.7 m (104.5 inches wide) (per wing)
WEIGHT	- 1723 kg (3,800 pounds) (including deployment structure)
PANELS	- 5 per wing (inboard panels are half covered with modules)
PANELS	- 20 total
MODULES	- 360 total
SOLAR CELLS	- 2x2 cm - 123,120 and
	- 2x6 cm - 41,040 TOTAL = 164,160*
SOLAR PANEL	
SIZE	- 2.7 m (104.3 inches long), 2.7 m (104.5 inches wide)
WEIGHT	- 66.2 kg (146 pounds) (including panel frame)
MODULES	- 20 per panel (inboard panels contain 10 modules each)
TOTAL CELLS	- 2x2 cm - 13,680 or
	- 2x6 cm - 4,560 (per panel)
SOLAR CELL MODULE (Both Types)	
SIZE	- .5 m (20.0 inches long), .63 m (24.625 inches wide)
WEIGHT	- 2.2 kg (4.93 pounds)
SERIES CELLS	- 114
PARALLEL CELLS	- 2x2 cm - 6 or
	- 2x6 cm - 2
TOTAL CELLS	- 2x2 cm - 684 or
	- 2x6 cm - 228
CELL INTERCONNECTOR	- 2x2 cm - Expanded Silver Mesh
	- 2x6 cm - Solder Plated Copper
CELL TO SUBSTRATE ADHESIVE	- .127 mm (0.005 inch) Silastic 140
SUBSTRATE	- Aluminum Facesheet/Aluminum Honeycomb
DIELECTRIC INSULATION	- .127 mm (0.005 inch) Micaply
SOLAR CELL	
TYPE	- N/P
SIZE	- 2x2 cm and
	- 2x6 cm (both 0.014 inch thick)
BASE RESISTIVITY	- 7 to 14 ohm-cm
CELL CONTACT	- AgTi, fully solder covered contacts
EFFICIENCY	- AMO, 28°C, 10 % bare, new

*Assumed 50 percent of modules have 2x2 cm cells and 50 percent have 2x6 cm cells.

Table 5.VI Physical Characteristics of ATM Solar Array

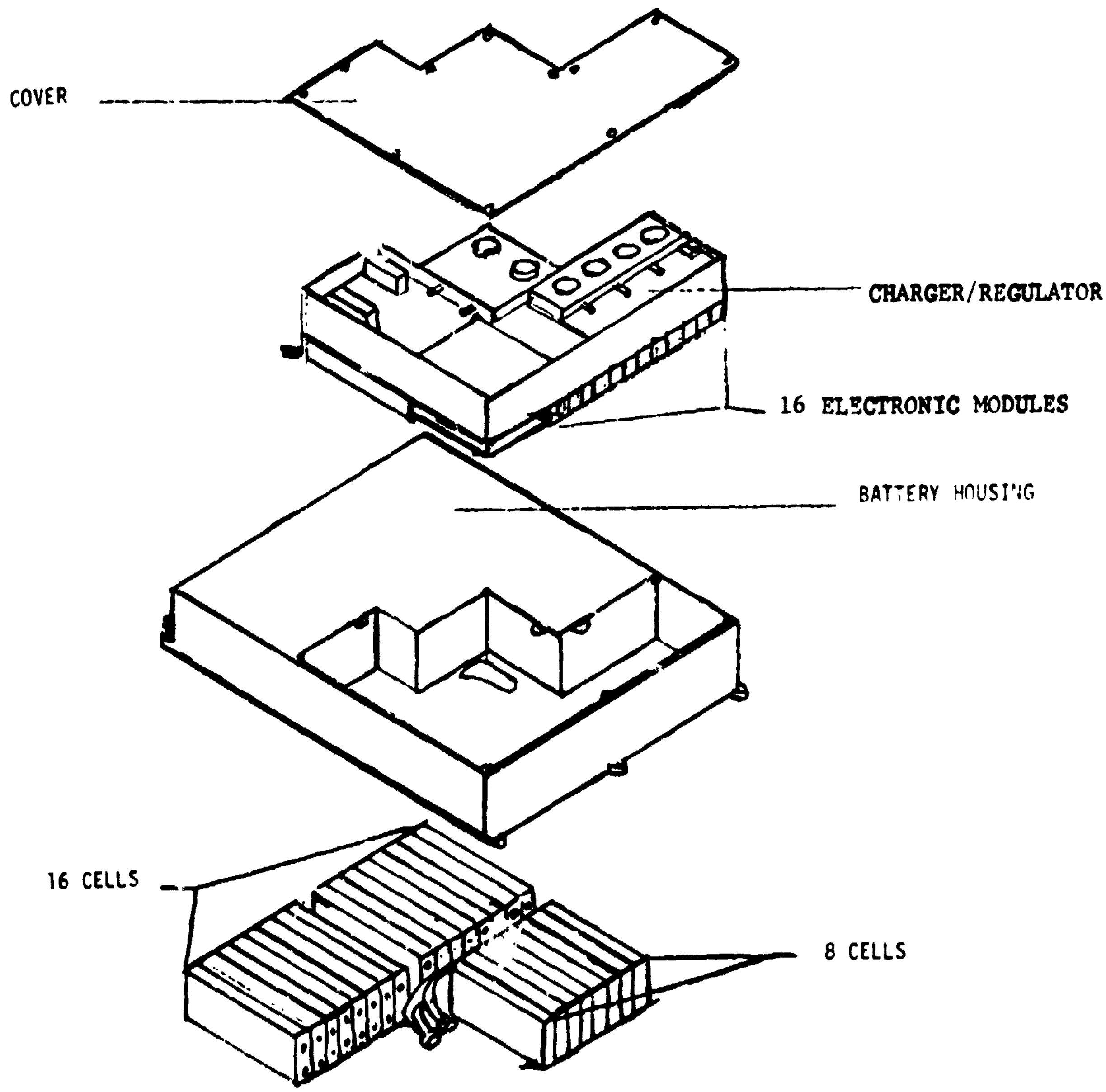


Figure 5.21 Charger Battery Regulator Modules

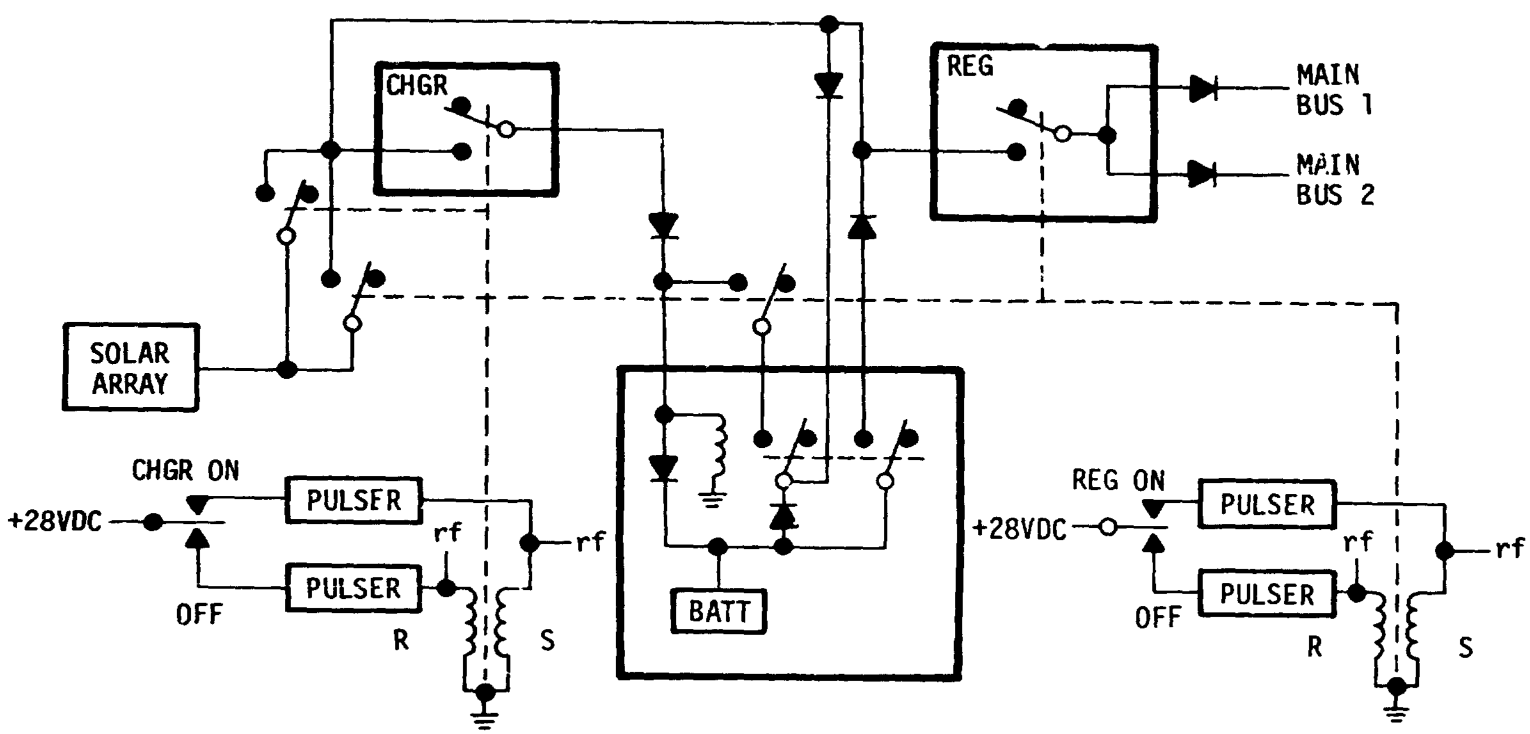


Figure 5.22 CBRM Functional Diagram

and current, battery temperature, charger current, battery voltage, and third electrode voltage of the battery to provide proper charge control (Figures 5.23 and 5.24). Charge termination occurred when the third electrode signal was greater than 200 mV, or the battery relay was opened at 51.5°C, or when array power was insufficient.

2 Battery. The 18 storage batteries were to supply continuous power flow during the dark portion of each orbit or during the day when vehicle was not sun oriented. Each CBRM battery was composed of 24 nickel-cadmium, 4 electrode, hermetically sealed cells connected in series. In addition to normal positive and negative power electrodes, the cells had a third electrode (Figure 5.24) which was used in charge control and a passive fourth electrode which was an oxygen and hydrogen recombination electrode.

The battery temperature operating range was 0°C to 30°C. However, operation at 30°C would cause significant capacity loss if operated for an extended period. Operation between 0°C and 20°C was therefore preferred. Thermal control in the form of a proportional heater (which operated between 0 and 10°C) was provided to prevent the battery temperature from going below 0°C. Heat was removed from the battery by passive cooling.

The batteries were rechargeable and the energy depleted during the dark portion of each orbit was replenished during the daylight portion of each orbit. The energy for charging was supplied by the solar array to the CBRM electronics where it was conditioned and utilized. The voltage output was 26.4 to 32.5 volts when discharged in the load range of up to 10 amperes. Each battery had a life requirement of 4000 cycles at a depth of discharge (DOD) of 30%.

3 Voltage Regulator. The regulator was a single-ended switching regulator circuit designed to convert the input voltage (25.5 to 80 Vdc) into a regulated output voltage. The output voltage was maintained between 27.1 Vdc at full load and 30.4 Vdc at no load with the output current limited to 20.0 amps maximum under output short circuit conditions. The regulator had average and peak output power capabilities of 235 and 415 watts, respectively. Power sharing between regulators was forced by a power sharing signal derived from redundant circuitry located in the power transfer distributor. Power was obtainable from either solar array source or battery, or both, and was converted to the regulator voltage that was fed through isolation diodes to redundant power buses in the power transfer distributor. The regulator provided protection to the bus from over-voltage if its output exceeded 31.8 Vdc. Any failure in the regulator power circuit resulted in zero or low output voltage, thus protecting the buses from high battery and solar array voltages.

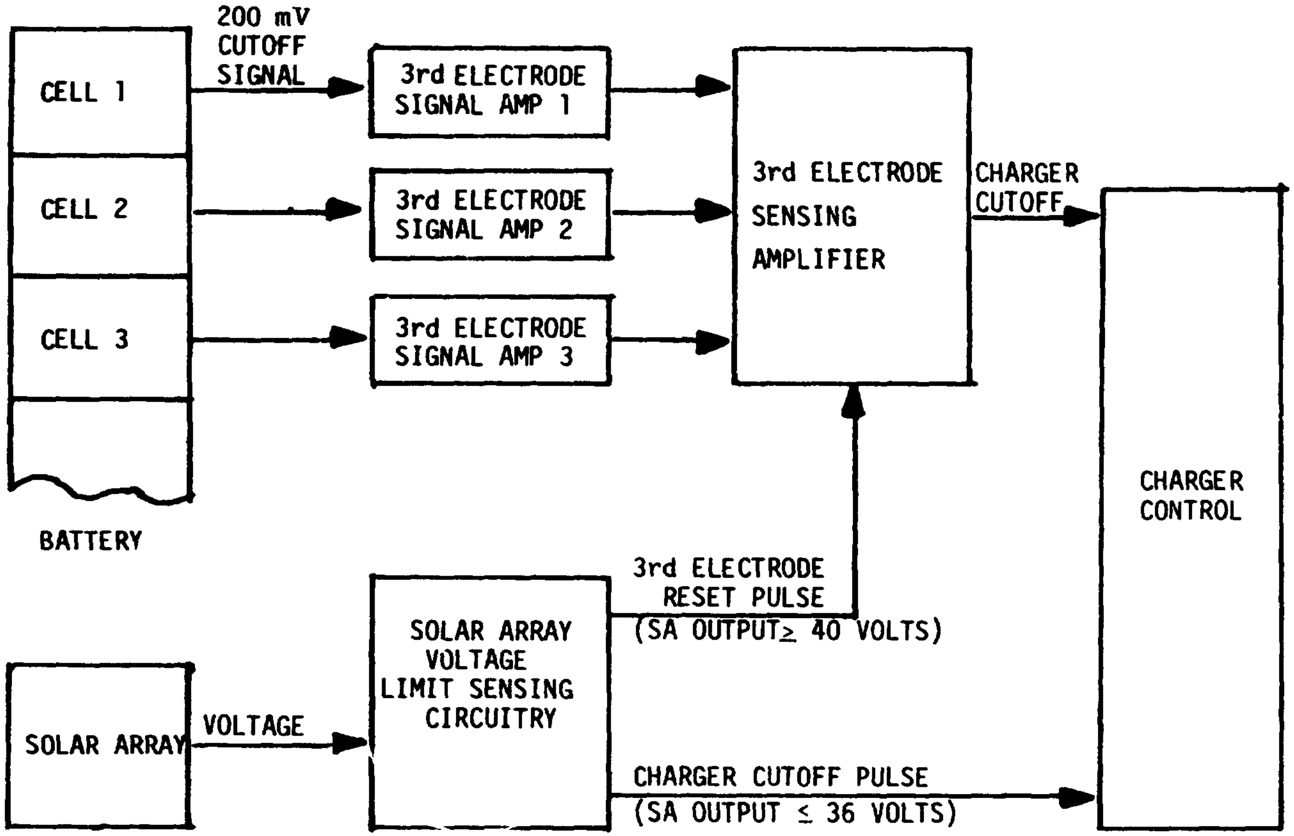


Figure 5.23 Charger Cutoff Block Diagram

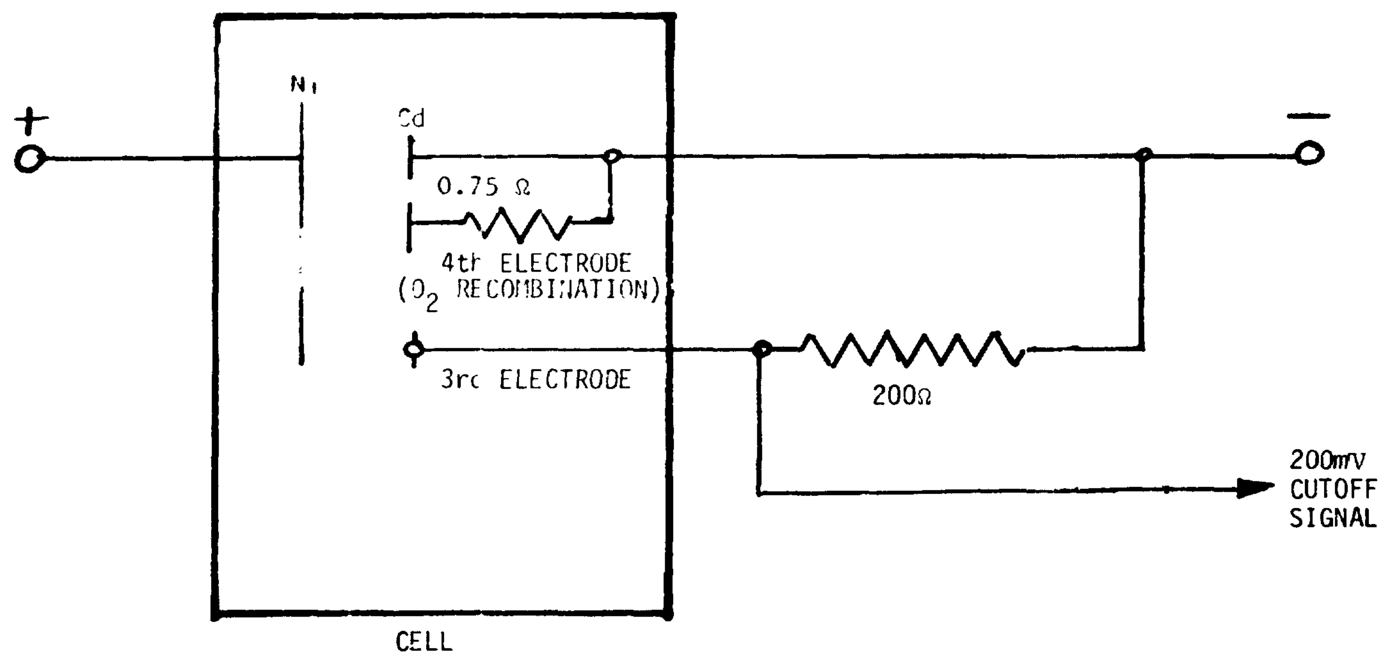


Figure 5.24 3rd Electrode Cutoff and 4th Electrode O_2 Recombination Simplified Diagram

c. Power Distribution.

(1) AM/OWS. The Power Distribution System received power from the AM Power Conditioning Groups at the AM Reg. buses.

The power Distribution System utilized two separate isolated DC bus systems. These systems were two wire systems with the exceptions that the OWS buses, the ATM buses, and the CSM buses utilized a common return bus system. The negative return bus system (Figure 5.5) was connected to vehicle structure at one point only, either the single point ground (SPG) in the AM or the vehicle ground point (VGP) in the CSM. All loads identified throughout the Skylab were powered from one of the buses on Figures 5.25 and 5.26. Circuit breakers in the AM Power Distribution System were located on STS Circuit Breaker Panels 201 and 202. The onboard controls and monitors for the AM Power Distribution System were located on STS Control Panels 205 and 206 with three exceptions. The three exceptions are: the AM transfer bus to the CSM bus interconnections were independently controlled from the CSM; the ON/OFF controls for the AM EREP buses were controlled from the MDA C&D Panel; and the AM Transfer bus to the ATM bus interconnections could also be opened in case of emergency by the ATM power off switch located on the ATM C&D Panel in the MDA.

The functions, interconnections, and controls associated with each bus in a set of isolated positive buses were identical. Loads were connected to each bus through protective devices, circuit breakers or fuses, to protect the distribution system.

Each EPS control bus received power directly from four of the eight AM PCG voltage regulator outputs; EPS control bus 1 from regulators 1 through 4 and EPS control bus 2 from regulators 5 through 8. The regulator output to EPS control bus connections were made through diodes in order to maintain bus isolation. The function of the EPS control buses was to provide the power source for critical loads. The EPS control buses were therefore hard-wire connected to the regulators such that power could not be removed from these buses by means of astronaut or ground controls. Loads supplied from the EPS control buses included: 1) equipment required for primary power system controls for PCGs 1 through 4 and for PCGs 5 through 8 were powered from EPS buses 2 and 1, respectively, as a precautionary design feature), 2) lighting required for astronaut egress from AM/MDA/OWS in an emergency, 3) Caution and Warning System equipments, and 4) Time Reference System equipments.

Each Reg. bus could be powered from any of the AM PCG voltage regulators but each regulator could be connected to only one of the Reg. buses at a time. The standard operating condition was four regulators supplying each bus. Power from the Reg. buses was distributed

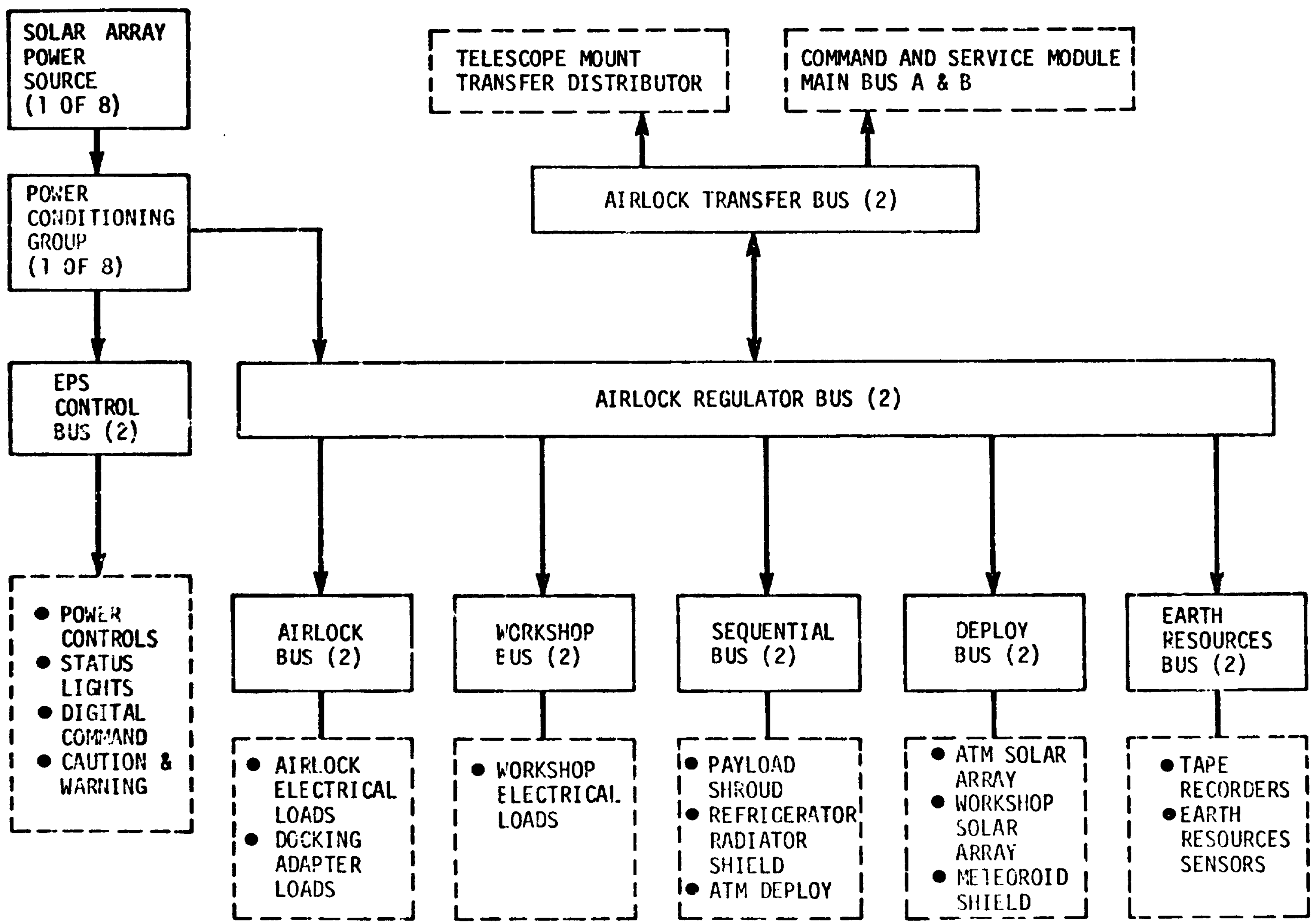


Figure 5.25 Simplified Block Diagram of AM/OWS/MDA Power Distribution

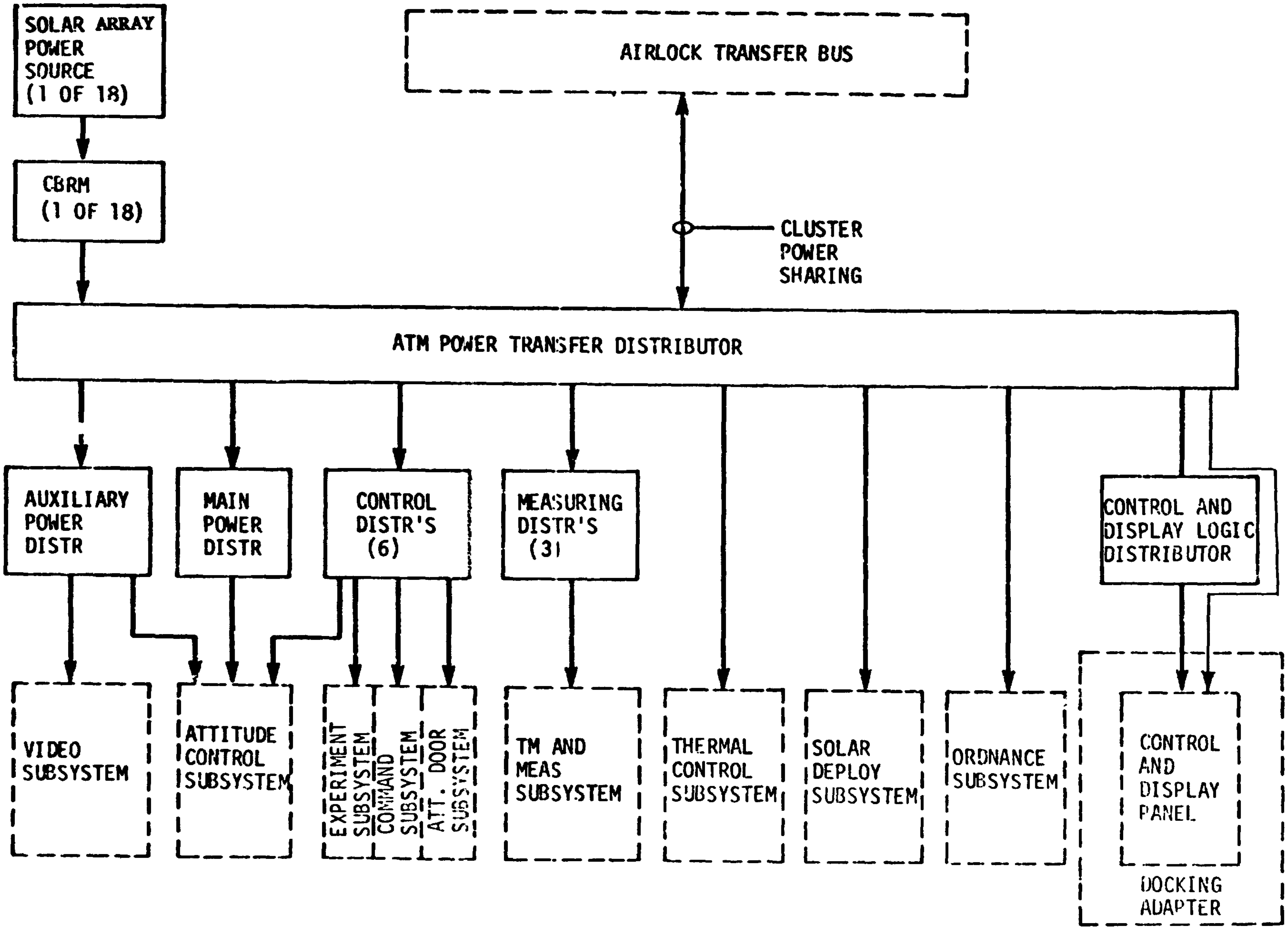


Figure 5.26 Simplified Block Diagram of ATM Power Distribution

to the AM buses and the transfer buses within the AM and to the OWS main buses in the OWS.

The AM buses provided power to all the loads in the AM except those which were connected to the EPS control buses. The AM buses also provided power to the loads in the MDA, to certain loads in the OWS, and to the Deploy, Sequential, and EREP buses.

The Sequential buses provided the power required for payload shroud jettison, OWS radiator shield jettison, and ATM deployment. The deploy buses provided the power required for the following: antenna deployment, OWS solar array deployment, OWS meteoroid bumper deployment, and ATM solar array deployment. The Deploy and Sequential buses were disabled after the sequential portions of the SL-1 mission, for purposes of safety.

The transfer buses provided the electrical power interface between the AM, ATM, and CSM. Bidirectional power transfer between the AM EPS and the ATM EPS was accomplished by connecting both the AM Reg buses and the ATM load buses to the transfer buses, Figure 5.6. The CSM, when present as pa· of the cluster, also had its power system normally connected to the transfer buses. Power for the CSM could therefore be supplied by either the AM or ATM EPS or by the parallel combination of the two EPS systems. The system having the highest voltage supplied the major portion of the cluster loads.

The EREP buses, located in the AM, provided power to the Earth Resources Experiments which were primarily located in the MDA.

The output of each voltage regulator could also be connected to either of the Reg buses by means of two controls. The PCG output bus select control connected the output to either Reg bus 1 or to Reg bus 2 when the PCG output ON/OFF control was in the ON position. The OFF position of the PCG output ON/OFF control isolated the regulator output from either of the Reg buses.

The output voltage level of each voltage regulator was controlled by two adjustment potentiometers, a fine adjust potentiometer and a Reg bus adjust potentiometer. The required switching of connections between the regulator, the Reg buses, and the adjustment pots were made by means of the PCG output bus select control and PCG output ON/OFF control. There was a fine adjust pot associated with each voltage regulator. The fine adjust potentiometer controlled the output level of each regulator relative to the other PCGs. This capability was designed so that variations between PCGs could be overcome, as well as possible contingencies such as module failures in a battery charger or regulator. There were only two Reg bus pots, one for each

Reg bus. The load sharing between the AM/OWS and the ATM power systems, when operated in parallel, was controlled by means of these AM Reg bus adjustment potentiometers. These potentiometers adjusted the overall AM Reg bus V-I curve with respect to the overall ATM load bus V-I curve.

The functions of the OWS bus 1, Reg transfer tie-bus 1, ATM/ transfer tie-bus 1, and AM bus 1 were straightforward. One feature to be noted is that a single Reg bus could supply power to both AM buses by means of the AM bus 1 and AM bus 2 switches (Figure 5.4).

All of the control functions described in this section, so far, with the exception of the adjustment pots, were controllable either by astronaut manual switching or by ground control commands. The type of control was dependent upon the setting of an astronaut manual control designated as the Power System Control switch. This Power System Control switch was located on control panel 205. Inflight control of the EPS by the various astronaut manual switches was obtained when the power system control switch was placed in the Manual position. When the switch was in the CMD (Command) position, control was possible only from the ground by means of DCS commands.

There were, however, several controls which were not controlled by the Power System Control Switch. The Power Disconnect switches 1 and 2 were for emergency power down of Reg buses 1 and 2, respectively. They were operational at all times by crew action only. Power Disconnect switch #1, when thrown to its Off position, disconnected the outputs of PCGs 1 through 4 and disconnected transfer bus #1 from Reg bus #1. Power Disconnect switch #2, when thrown to its Off position, disconnected the outputs of PCGs 5 through 8 and disconnected transfer bus #2 from Reg bus #2. The Electrical Ground Switch, which controlled the location of the single point ground, was also indpendent of the Power System Control switch position. The connections between the transfer buses and the CSM buses were controlled from the CSM and were independent of the AM Power System Control. The connections between the ATM buses and the AM transfer buses could also be opened in an emergency by a Power Off switch on the ATM C&D panel which was independent of the Power System Control Switch. The connections between the AM buses and the Sequential and Deploy buses were normally controlled automatically by the Sequential and Deploy systems, respectively. There were Sequential and Deploy switches on the STS panel to provide backup control for these buses.

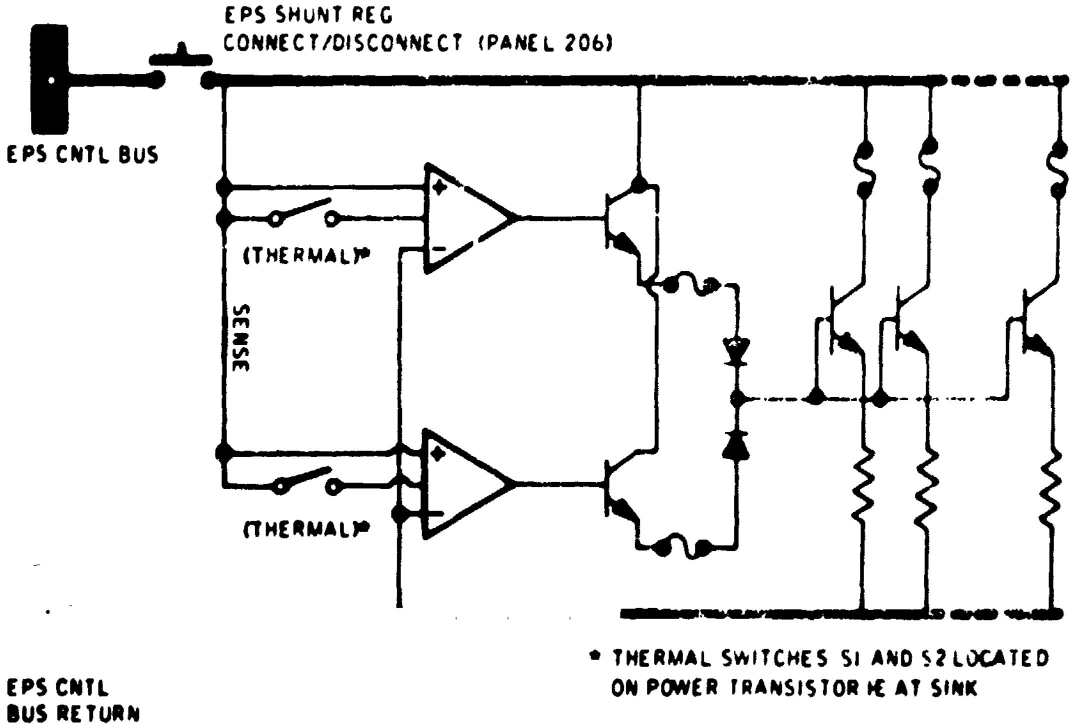
In addition to the control logic functions discussed above, the Reg Bus Tie circuit breakers between Reg bus 1 and Reg bus 2 could also be considered as part of the control logic. By manual crew control of these two 26.4 amp circuit breakers the two Reg buses could be operated in parallel. Parallel operation could be used to reduce the effects of unbalanced system 1 and 2 load demands or unbalanced system 1 and 2 power availability. The normal operating mode was with the Reg Bus Tie circuit breakers closed.

(a) Power Return and Grounding. The electrical power distribution system, as previously discussed, consisted of a two wire system employing separate buses for both power feeders and negative returns. The return buses were tied to vehicle structure at only one point. This connection to vehicle structure was accomplished in one of two locations. During periods when the CSM/MDA interface connectors were not mated, the grounding was via the SPG in the AM (Figure 5.5). During periods when the CSM was present as part of the OA, with the CSM/MDA interface connectors mated, grounding was via the VGP in the CSM structure. The connection to the VGP in the CSM was automatic when the CSM/MDA interface connectors were mated. The control switching in the AM was used to connect and disconnect the SPG in the AM. Control of the SPG connection in the AM was by either crew manual operation or by DCS command at all times.

(b) Power Feeder Design and Protection. The power feeder lines between the various power and return buses consisted of multiple wires which were selected both for current carrying capacity and voltage drop requirements. Circuit breakers were incorporated in the positive feeder lines between buses located in different Skylab modules (see Figure 5.4) with a separate set of breakers located in each of the modules. In addition to these circuit breakers, adequate circuit protection was incorporated into power distribution circuitry to all equipment powered from the AM EPS buses. The circuit protection was comprised of circuit breakers compatible with load requirements which protected the power distribution wiring from damage resulting from system overloads or short circuit conditions.

(c) Shunt Regulator. The function of the shunt regulator was to prevent the occurrence of an overvoltage on the AM EPS buses as the result of a PCG voltage regulator module failure. There were two shunt regulators in the AM EPS. One was connected to each of the EPS control buses.

A shunt regulator, Figure 5.27, consisted of a sense circuit, a drive circuit, and a transistor regulator band of parallel power transistors. The sense circuit monitored the terminal voltage of the shunt regulator which was the EPS control bus voltage. When this voltage exceeded a preset level in the range of 30 to 32 volts, the sense circuit provided an output current signal to the drive circuit. The drive circuit amplified this current input and drove the base circuit of the parallel regulator transistors. Each regulator transistor amplified its base current producing an increased collector



MAXIMUM TURN-ON TIME · 10 MICROSECONDS

MINIMUM TURN-ON VOLTAGE SENSE LEVEL · 31.5 VDC

MAXIMUM TURN-ON VOLTAGE SENSE LEVEL · 32 VDC

CURRENT - TIME CAPABILITY:

200 AMPERES FOR 0.05 SECONDS

40 AMPERES FOR 100 SECONDS

Figure 5.27 Shunt Regulator Schematic

current flow. Since the regulator transistors were connected across the EPS control bus, their increased collector currents produced an increased load on the bus. The effect of this increased load was to reduce the bus voltage because of the loading effect on the power source and the increased voltage drops from the power source to the bus.

The regulation capability of the shunt regulator was established by its V-I characteristic. Below a specific sense voltage, the shunt regulator drew negligible current (less than 100 milliamperes). Above that sense voltage its V-I characteristic exhibited a dynamic impedance in the range of 0.67 to 6.7 milliohms. This very low dynamic impedance was produced by the high gain from the sense circuit input voltage to the transistor regulator bank load current. This high gain, and the corresponding low dynamic impedance provided the shunt regulator with the capability to draw sufficient load current to limit the bus voltage to the desired level. At the same time, the current drawn by the shunt regulator insured the rapid clearing of the fuses in any failed module of the voltage regulator.

(d) Manual and DCS Control Functions. Primary control of both EPSs was by either manual control provisions installed on instrument panels or by DCS or DAS commands from ground control. The functions, which were controlled, included those associated with PCG and CBRM control, and those associated with power distribution bus control.

(e) Display and Telemetry Parameters. A number of analog parameters were displayed on meters installed on the instrument panels. These parameters were displayed to indicate instantaneous power system status to the astronauts and to assist the astronauts in their manual management of the system. A greater number of parameters were monitored and transmitted by means of telemetry to ground control to aid in ground performance and control analysis and their management.

(2) ATM. The ATM electrical power and distribution subsystems performed essentially the same functions as those of the AM/OWS. Thus, these following paragraphs will mainly cover areas where ATM differed from AM/OWS.

The operational modes of each system were similar except for control limits. The output of each CBRM was connected in parallel through isolation diodes and connector buses to the two major ATM load buses in the power transfer distributor (Figure 5.4). Each bus was capable of supplying all electrical requirements, independently.

Control and monitor circuitry of CBRMs provided the capability for both internal and remote control, automatic malfunction detection, automatic clearing, astronaut display warning, and telemetry data. The CBRMs were controlled from the Control and Display panel in the MDA through the use of switches or the DAS. Each CBRM contained semiconductor switching devices to operate remote indicators on the C&D panel for critical parameters. The distribution subsystem provided an interface and integration of electrical functions among all associated components, assemblies, subsystems, and modules. Distribution of the power, commands, and indications throughout was accomplished by the network as indicated in Figures 5.4 and 5.6 , which allowed several assemblies and subassemblies access to a common distribution system. The distribution system provided the capability to operate the ATM EPS in parallel with the AM EPS; to manage and evaluate the power by crew and/or ground station; to provide power and control logic circuitry to the various ATM subsystem loads; and to perform integrated prelaunch test and checkout, module testing, and launch operations.

The dual output lines of each CBRM were fed to the power transfer distributor so that all CBRMs feed two collector buses (see Figure 5.4). Diode isolation was provided on the input lines so that the load buses were electrically isolated from each other as well as being physically separated. Each redundant bus was capable of providing the total power required by the ATM loads. The collector buses fed the main buses to provide power to circuits and loads required during initial power up and deployment sequences.

Redundant subsystem buses were established to facilitate power management, power evaluation and an integrated system operation. Several methods of control were used to ensure that the buses could be turned "On" or "Off" during manned and unmanned modes of operation. At launch, the main buses would be "On" and the subsystem buses would be "Off." Programmed commands from the Saturn Instrument Unit flight sequencer would be issued via the OWS to energize all subsystem buses during the initial orbital phase. Backup commands were by the AM DCS. The ATM DAS and C&D panel switch commands were primarily for the manned modes.

When the subsystem buses were activated in the power transfer distributor, power was immediately distributed to the other 12 distributors. Each redundant subsystem bus was capable of providing the total power required by its subsystem. Redundancy was maintained by distributing the power through two separate connectors and cables. Each positive polarity power feeder line was fused to provide fire protection against a shorted condition. The current carrying capacity of all cabling was de-rated by 50% for space use. The wire size and number of wires used were designed to meet interface voltage requirements, and to maintain the bus voltage level at 26.0 Vdc to 30.5 Vdc.

Each distributor maintained power redundancy, and bus isolation. The distributors were used to aid in routing of all signals, to contain the logic and switching required by the ATM subsystems, and to contain any special electronics to ensure proper operation.

Power was routed to ATM loads on a two wire system with the positive polarity feeders protected by fuses (see Figure 5.4). Where feasible, redundancy was maintained through separate connectors and diodes, which were inside the load, to maintain bus isolation. When items of equipment did not contain isolation diodes, the distributor provided diode isolation. The power return remained isolated from structure except in those items which were waivered. Electrical bonding and grounding of the ATM electrical equipment were accomplished at grounding straps.

The number of wires and wire size in the AM/ATM power transfer cables were selected to ensure the voltage level of 28.3 Vdc to 30.5 Vdc at the interface. The primary control for connecting and disconnecting the power feeders was in the AM; but when the ATM power "Off" command was given, a command to disconnect the power feeders was sent. The single point ground for the ATM had been established in the AM by connecting the ATM power return to the AM power return (Figure 5.3). When the CSM docked to the MDA, the single point ground was transferred to the CSM.

If the ATM power had to be turned off in an emergency, control was provided by the ATM power switch on the ATM C&D panel. A locked switch requiring a positive action to activate was used. Activating the switch provided power from the ATM main buses for the following functions: a signal was sent to the AM to disconnect the power from the transfer buses; all the power relays controlling the redundant subsystem buses were reset; and a 300 millisecond timing oscillator was started which turned off all 18 CBRMs.

The ATM EPS interfaced with the cluster Caution and Warning subsystem in the AM and provided two warning signals which were ATM BUS 1 LOW and ATM BUS 2 LOW. The signals were activated when the respective bus voltage fell to 25.0 + 0.5 Vdc. There were no indications for high voltage as the regulators were automatically disconnected if they reached 31.8 $\pm$ 0.2 volts. The C&W bus power was provided to the ATM by the AM.

The capability for control and monitoring by the crew and ground stations was provided by the measurement and telemetry system. The subsystem had three measuring distributors and 12 J-box assemblies that were associated primarily with assemblies of the telemetry system. The measuring distributors took the indications and measurements, such as, temperature, current, pressure, and voltage levels from the transducers and ATM equipment and routed them to the proper telemetry assembly for ultimate transmittal to the ground receiving stations. The J-boxes were used to branch single outputs from the multiplexers and experiment packages to redundant PCM/DDAS telemetry equipment.

Controlled monitoring operation and testing was through the ATM command system. The methods of control were: the Digital Address System (DAS) and switches on the C&D panel; ground station rf uplink via the rf command receivers and rf command decoders. The primary method of control by the crew was through the use of C&D panel switches, with the DAS keyboard used as backup. Control was provided by four switch selectors which issued discrete pulse commands to relays in the ATM. The rf uplink commands and DAS commands were integrated with the switch selectors. The crew was provided with a ground command enable/inhibit switch to disable the rf capability during the manned mode, if desired. The two digital computers were also controlled by this command system. The DAS keyboard converted an octal code input to a binary output pulse. The octal code was arranged in such a way that the four switch selectors and two digital computers would receive the address commands simultaneously but only one of them would be enabled. When the address was verified, an execute command was given to the item enabled.

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d. Skylab Caution and Warning System. The design features and major components of the C&W System are described below; detailed description of this system is contained in the Skylab Caution and Warning Technical Manual, MSFC 40M35701.

(1) C&W System Operation. The Skylab C&W System consisted of C&W Systems installed in both the SWS and the CSM. Each system provided the crew with visual displays and audio tones when selected parameters reached out-of-tolerance conditions. In the docked configuration, the two C&W Systems interfaced by means of discrete contact closures to provide for cluster wide monitoring of selected parameters. The C&W System equipment used to monitor these parameters is depicted in block diagram form in Figure 5.29. The SWS C&W System control and display panels are shown in Figure 5.30.

(a) SWS C&W System. The system monitored the performance of specified vehicle systems and alerted the crew to hazards or out-of-limit conditions. The SWS C&W System utilized two independent subsystems, a caution and warning subsystem for monitoring various system parameters and an emergency subsystem for detecting fire or rapid loss of pressure. A list of the 76 cluster parameters monitored by the SWS C&W System as well as the nominal trip points is enumerated in Table 5.VII.

(b) CSM C&W System. The CSM contained a separate C&W System for monitoring thirty-six critical system parameters in the CSM. An out-of-tolerance condition in the CSM resulted in the generation of audio tones and the illumination of visual displays in the CM. In addition, the CSM C&W System provided redundant contact closures to the SWS C&W System. Upon receiving the CSM inputs, the SWS C&W System activated the corresponding SWS warning audio tone and illuminated the visual displays to alert the crew so that corrective action could be taken. The audio tones continued until the SWS C&W System was reset; however, the CSM closure remained until reset from within the CM. The CSM C&W equipment and operation is discussed in detail in the Skylab Operations Handbook, Volume I, SM2A-03-SKYLAB-(1).

(2) Major SWS C&W Components. The SWS C&W System was made up of the following major components:

(a) Circuit Breaker Panel 202. Circuit Breaker Panel 202 housed the SWS C&W System related circuit breakers. This panel was located in the STS. Fourteen circuit breakers were utilized for controlling power to various components of the C&W System. These circuit breakers provided power to the redundant components within the system from two independent energized buses.

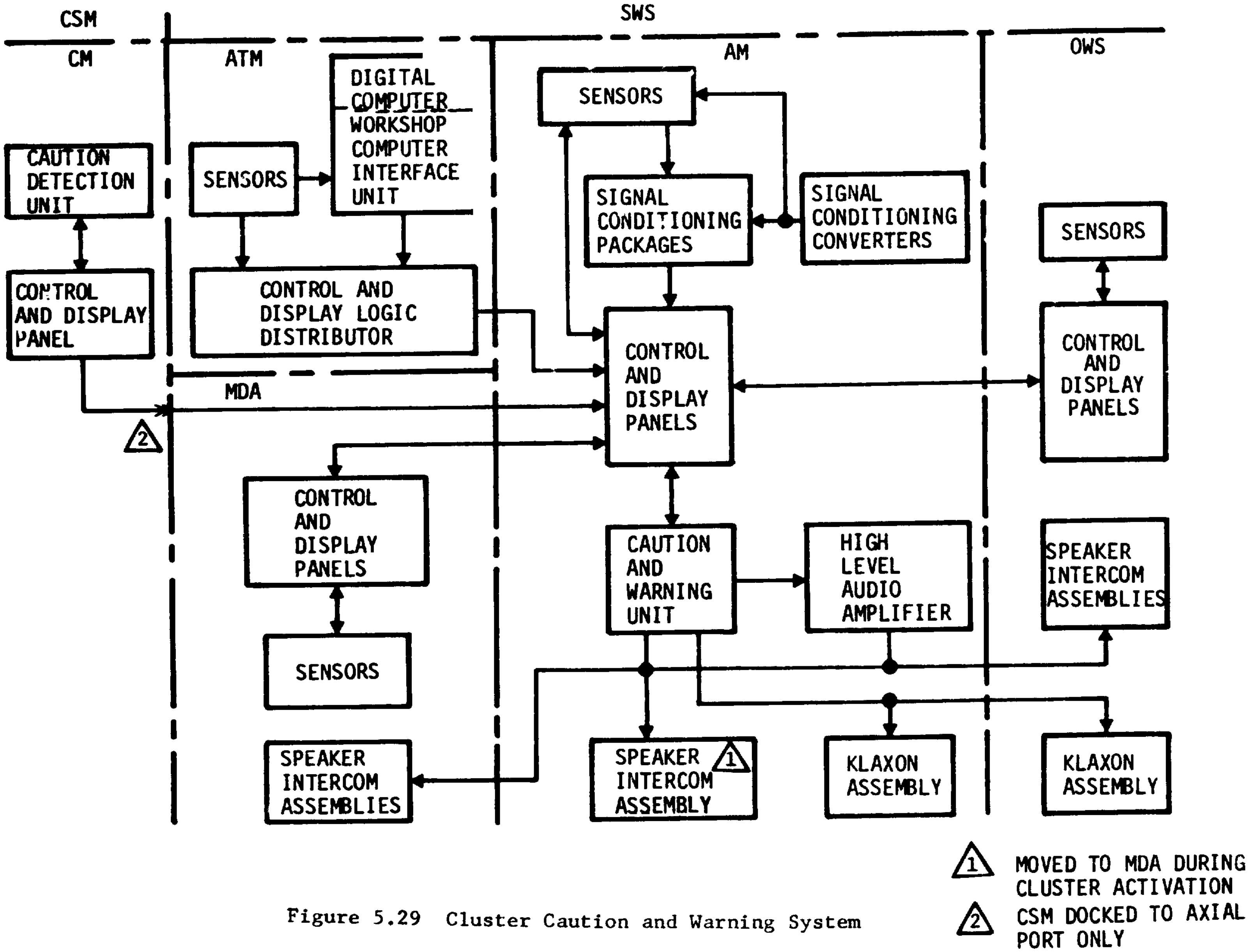

Figure 5.29 Cluster Caution and Warning System

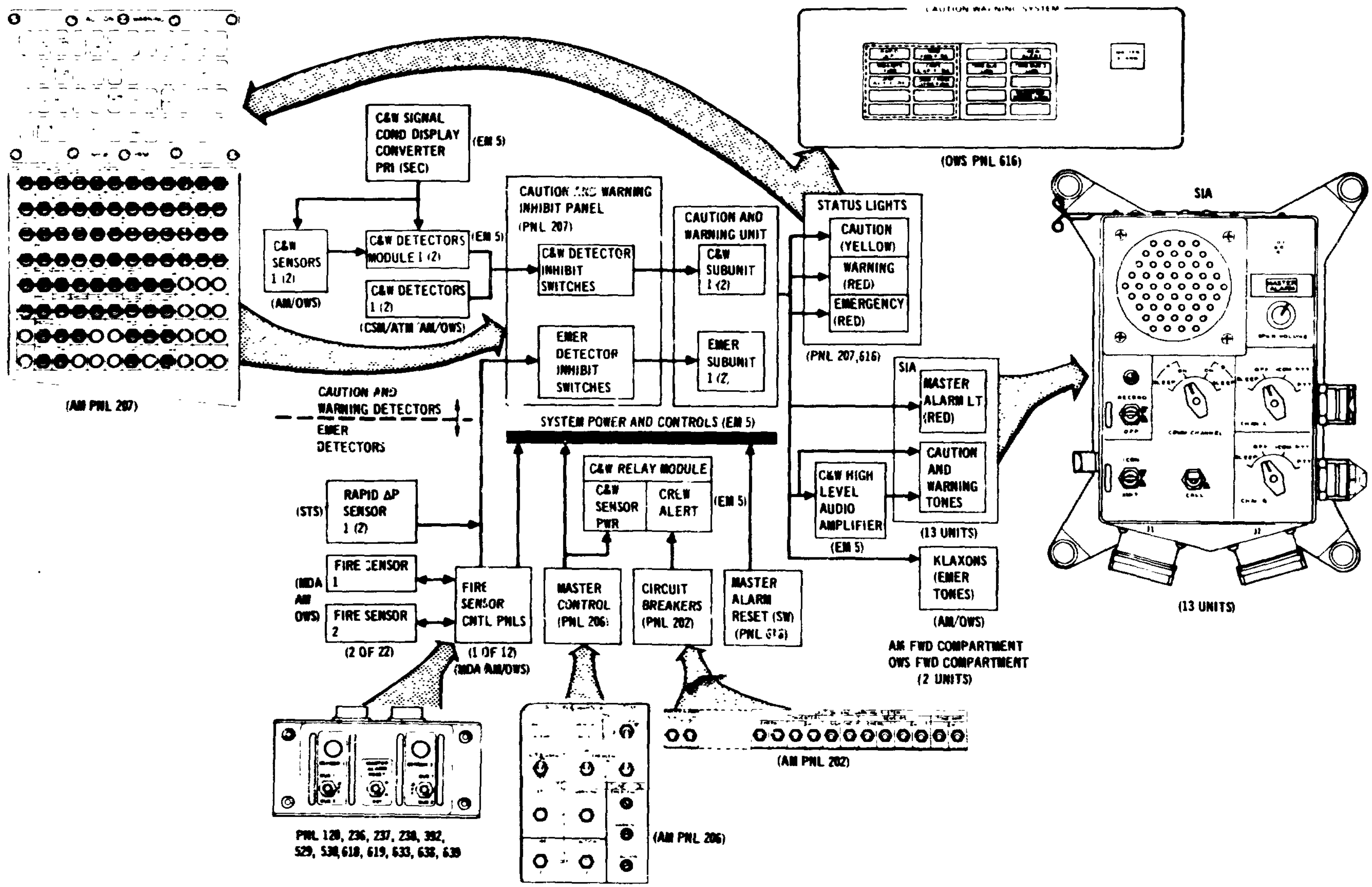

Figure 5.30 Caution and Warning Controls and Displays

ITEM/PARAMETER	MONITORED MODULE	CRITICALITY (SEE NOTE 1)	LIGHT LABELING	C&W TRIP POINTS
AM-ECS				
1. Sieve A Bed 1/2 2. Sieve B Bed 1/2	AM	C	SIEVE TEMP HIGH	425DEG. F$\leq$T$\leq$450DEG. F.
3. PPO_2 1 4. PPO_2 2	AM	W	PPO_2 LOW	145.2 mmHg$\leq$ PPO_2 $\leq$169.6mmHg
5. Pri Cool Pump 1 6. Pri Cool Pump 2 7. Pri Cool Pump 3	AM	W	PRI COOL FLOW	N/A
8. Sec Cool Pump 1 9. Sec Cool Pump 2 10.Sec Cool Pump 3	AM	W	SEC COOL FLOW	N/A
11.Cluster Pressure	AM	W	CLUSTER PRESS LOW	4.5 PSIA$\leq$P$\leq$4.7 PSIA
12.Sieve A PCO_2 13.Sieve B PCO_2	AM	C	SIEVE OUT $PPCO_2$ HIGH	2.87 mmHg$\leq PCO_2 \leq$5.93 mmHg
14.Sieve A Gas Flow 15.Sieve B Gas Flow	AM	C	SIEVE FLOW	17.3 CFM$\leq$F$\leq$24.9 CFM
16.Sieve A Timer 17.Sieve B Timer	AM	C	SIEVE TIMER	Timer Power Interrupt $\geq$45 MS
18.OWS Gas Flow	AM	C	OWS GAS INTER CHG	35 CFM$\leq$F$\leq$55 CFM
19.Condensate Tank ΔP	AM	C	CNDST TANK ΔP	0.3 PSID $\leq \Delta P \leq$0.8 PSID

Table 5.VII Caution and Warning System Parameters

ITEM/PARAMETER	MONITORED MODULE	CRITICALITY (SEE NOTE 1)	LIGHT LABELING	C&W TRIP POINTS
20.Pri Cool 47 DEG. Valve	AM	C	PRI COOL TEMP LOW	35.1 DEG. F≤T≤40.9DEG. F.
21.Sec Cool 47 DEG. Valve	AM	C	SEC COOL TEMP LOW	35.1 DEG. F≤T≤40.9DEG. F
22.Pri Cool Loop Temp	AM	C	PRI COOL TEMP HIGH	114.2 DEG. F≤T 125.8 DEG. F
23.Sec Cool Loop Temp	AM	C	SEC COOL TEMP HIGH	114.2 DEG. F≤T≤125.8 DEG. F
INTEGRATED EPS				
24.Reg Bus 1 Low	AM	W	REG BUS 1 LOW	24.5 VDC<V<25.5 VDC
25.Reg Bus 1 High	AM	W	REG BUS 1 HIGH	30.38 VDC<V<31.62 VDC
26.Reg Bus 2 Low	AM	W	REG BUS 2 LOW	24.5 VDC<V<25.5 VDC
27.Reg Bus 2 High	AM	W	REG BUS 2 HIGH	30.38 VDC≤V≤31.62 VDC
28.ATM Bus 1 Low	ATM	W	ATM BUS 1 LOW	24.5 VDC≤V≤25.5 VDC
29.ATM Bus 2 Low	ATM	W	ATM BUS 2 LOW	24.5 VDC≤V≤25.5 VDC
30.C&W Power 1	AM	C	C&W POWER	3.7 VDC≤V≤ 4.3 VDC 23 VDC ≤ V≤ 25 VDC
31.C&W Power 2	AM	C		3.7 VDC≤V≤ 4.3 VDC 23 VDC≤V≤ 25 VDC
32.C&W Sig Cond Power	AM	C		26 VDC<V<22 VDC ± 2% -22 VDC≤V≤-26 VDC ± 2% 5.2 VDC≤V≤ 4.8 VDC ± 2%

Table 5.VII (cont.)

ITEM/PARAMETER	MONITORED MODULE	CRITICALITY (SEE NOTE 1)	LIGHT LABELING	C&W TRIP POINTS
33.Emerg Power 1	AM	C	EMERG POWER	23 VDC $\leq V \leq$ 25 VDC 3.7 VDC $\leq V \leq$ 4.3 VDC
34.Emerg Power 2	AM	C		23 VDC $\leq V \leq$ 25 VDC 3.7 VDC $\leq V \leq$ 4.3 VDC
35.Emerg Sensor 1 36.Emerg Sensor 2	AM	C	EMERG SENSOR POWER	24.5 VDC $\leq V \leq$ 25.5 VDC
37.OWS Bus 1 Low	OWS	C	OWS BUS 1 LOW	23.03 VDC $\leq V \leq$ 23.97 VDC
38.OWS Bus 2 Low	OWS	C	OWS BUS 2 LOW	23.03 VDC $\leq V \leq$ 23.97 VDC
39.Battery 1 70% D.O.D. 40.Battery 2 70% D.O.D. 41.Battery 3 70% D.O.D. 42.Battery 4 70% D.O.D. 43.Battery 5 70% D.O.D. 44.Battery 6 70% D.O.D. 45.Battery 7 70% D.O.D. 46.Battery 8 70% D.O.D.	AM	C	BAT CHARGE LOW	N/A
ATM-ACS				
47.ACS-Overate	ATM	W	CLUSTER ATT	N/A
48.ACS-Thruster Stuck	ATM	W		N/A
49.ACS-CMG Saturate	ATM	C	ACS MALF	N/A

Table 5.VII (cont.)

ITEM/PARAMETER	MONITORED MODULE	CRITICALITY (SEE NOTE 1)	LIGHT LABELING	C&W TRIP POINTS
50.ACS-Auto TACS Only Option	ATM	C	ACS MALF	N/A
51.ACS-2nd/3rd Rate Gyro Failure	ATM	C		N/A
52.ACS-Computer Self Test Failure	ATM	C	COMPUTER MALF	N/A
53.Computer X-Over	ATM	C		N/A
54.ATM Coolant Fluid Temp	ATM	C	ATM CNST THERM	44.9DEG. F$\leq$T$\leq$45.1DEG. F. 54.9DEG. F$\leq$T$\leq$55.1DEG. F.
55.ATM Coolant Htr Temp	ATM	C		149.64DEG. F$\leq$T$\leq$150.36DEG.F.
56.ATM Coolant Pump ΔP	ATM	C		24 PSID$\leq \Delta P \leq$ 26 PSID
EXTRAVEHICULAR ACTIVITY				
57.EVA LCG-1 Pump ΔP	AM	W	EVA 1	2.5 PSID$\leq \Delta P \leq$ 5.5 PSID
58.EVA LCG-1 H_2O In Temp	AM	W		31.986DEG. F$\leq$T$\leq$35.014DEG. F.
59.EVA LCG-2 Pump ΔP	AM	W	EVA 2	2.5 PSID$\leq \Delta P \leq$5.5 PSID
60.EVA LCG-2 H_2O In Temp	AM	W		31.986DEG. F$\leq$T$\leq$ 35.014DEG.F.
MISCELLANEOUS				
61.CSM 1 62.CSM 2	CSM	W	CSM	N/A

Table 5.VII (cont.)

ITEM/PARAMETER	MONITORED MODULE	CRITICALITY (SEE NOTE 1)	LIGHT LABELING	C&W TRIP POINTS
63.Crew Alert 1 64.Crew Alert 2	AM AM	W W	CREW ALERT (R)	N/A
EMERGENCY				
65.MDA/STS Fire 1 66.MDA/STS Fire 2	MDA/STS MDA/STS	E E	MDA STS FIRE (R)	△4 32 - 38 counts/sec
67.AM AFT Fire 1 68.AM AFT Fire 2	AM AM	E E	AM AFT FIRE (R)	△4 32 - 38 counts/sec
69.OWS Fwd Fire 1 70.OWS Fwd Fire 2	OWS OWS	E E	OWS FWD FIRE (R)	△4 32 - 38 counts/sec
71.OWS Exp Fire 1 72.OWS Exp Fire 2	OWS OWS	E E	OWS EXP FIRE (R)	△4 32 - 38 counts/sec
73.OWS Crew Qtrs Fire 1 74.OWS Crew Qtrs Fire 2	OWS OWS	E E	OWS CREW QTRS FIRE (R)	△4 32 - 38 counts/sec
75.Rapid ΔP 1 76.Rapid ΔP 2	AM AM	E E	RAPID ΔP (R)	$.10\ PSI/MIN \leq \frac{\Delta P}{\Delta T} \leq .11 PSI/MIN$

NOTES: 1 - E = Emergency, W = Warning, C = Caution
2 - Brackets denote use of 'or' gates to minimize channel complexity.
3 - (R) denotes items repeated in OWS.
△4 - Fire sensor trip point is adjustable from 25 counts/sec to 75 counts/sec.

Table 5.VII (cont.)

(b) Control and Display Panels. A total of fifteen separate control and display (C&D) panels were provided in the SWS for control, display, operation, and testing of the caution & warning and emergency subsystems. Three of these panels were used for control and display of both subsystems; whereas, the remaining twelve were used for control and display of the fire detection portion of the emergency subsystem.

1 Control and Display Panel 206. The major power and control switches for the SWS C&W System were located on Panel 206 in the STS. The master alarm red telelight switch was illuminated when either a caution, warning, or emergency parameter was activated. When depressed, the master alarm telelight switch provided a reset signal to the C&W unit electronics to terminate the audio tones, extinguish all master alarm telelight switches and master alarm status lights, and remove the telemetry closures. In the emergency subsystems, this reset signal also extinguished the parameter identification lights when the parameters had returned within limits. The memory recall amber telelight switch was used to indicate that caution and/or warning parameter(s) which activated the C&W subsystem has been stored in memory. Depressing the memory recall telelight switch caused the identification light(s) to be illuminated for the parameter(s) which were stored in memory. This provided for the identity of short term C&W subsystem activations after the fact. The clear switch erased the memory circuitry in the C&W unit and extinguished the recall telelight switch. Three power switches were provided for powering the SWS C&W System. One switch was used to control power to the C&W subsystem and the other two switches were used for the emergency subsystem. Four test switches were provided for testing the C&W subsystem electronics, audio tone, and visual displays. Three volume controls were also provided for controlling the intensity of the emergency, warning, and caution tones.

2 Display and Inhibit Switch Panel 207. The parameter identification lights and inhibit switches were located on Panel 207, also in the STS.

There were forty parameter identification lights used to aid the crew in identifying which parameter or system had gone out-of-tolerance. Emergency and warning parameter lights were color coded aviation red while caution parameter lights were colored aviation yellow. Each display had two bulbs for redundancy, with each bulb being driven by separate power sources.

Each parameter monitored by the C&W System had a corresponding inhibit switch(s) on Panel 207. The inhibit switches were used to disable a malfunctioning circuit or input signal without disabling other active parameter inputs. They could also be used to determine the nature of the malfunction in those cases where more than one parameter shared a common identification light. There were 76 double-pole single-throw inhibit switches utilized on this panel.

3 OWS Repeater Panel 616. This panel was located in the Experiment Compartment of the OWS. The panel contained one master alarm reset telelight switch (aviation red) which performed the same function as the master alarm telelight switch on AM Panel 206.

Ten parameter identification lights were utilized to aid the crew in identifying various parameters of systems that had gone out-of-tolerance. Each display contained two bulbs which were powered from separate power sources. The lights were color-coded the same as those appearing on AM Panel 207.

4 Fire Detection Control Panels. The fire sensor control panels (Panels 120, 236, 237, 238, 392, 529, 530, 618, 619, 633, 638, and 639) provided the controls for operation and test of the fire sensor assemblies. A typical panel is shown in Figure 5.30.

Each panel had the capability of controlling two sensors. Two power switches were provided, one for each sensor, which allowed manual selection of one of two normally energized buses capable of supplying power to the respective sensor. A master alarm reset/test switch was provided for testing the sensor(s) and resetting the SWS C&W System. A red display lamp was provided for each of the two sensors which illuminated upon activation of the sensor and remained illuminated until power was momentarily removed from the sensor. The bulbs and lenses of the panels and the panels themselves could be replaced inflight. Two spare panels (complete with lenses and bulbs) and eight lens and bulb assemblies, were stowed in the OWS for inflight replacement. In cases where one panel controlled only one sensor, a clip was provided for covering the unused control and display. When both sensors were energized, the panel dissipated 5.5 watts of power.

(c) Caution and Warning Unit. The C&W unit contained redundant C&W subunits and redundant emergency subunits. Each subunit was powered from a normally energized bus and was protected by an independent circuit breaker. Each C&W subunit utilized 36 caution and 26 warning parameter inputs and provided 22 caution and 17 warning outputs for parameter identification lights. Each emergency subunit had 12 parameter inputs and provided 12 outputs for parameter identification lights. The capacity of the C&W unit, including growth capability, is shown in Figure 5.31.

INPUT TYPE	INPUT CAPACITY**					
		GATES				
	CHANNELS	SINGLE	"2 OR"	"3 OR"	"8 OR"	TOTAL
AM CAUTION	16	8 ***	5	2	1	32
*OWS CAUTION	4	4 ****	0	0	0	4
AM WARNING	11	4	2	4	1 ***	28
*OWS WARNING	1	0	1	0	0	2
OPTIONAL-AM CAUTION OR WARNING	7	2	5 ***	0	0	12
*OPTIONAL-OWS CAUTION OR WARNING	1	0	1	0	0	2
*EMERGENCY-FIRE	5	0	5	0	0	10
*EMERGENCY-PRESSURE	1	0	1	0	0	2

NOTES:

*THESE INPUT TYPES CAUSE IDENTIFICATION LIGHT OUTPUTS FOR THE OWS IN ADDITION TO THOSE ON THE AM CAUTION AND WARNING SYSTEM PANEL.

**THE QUANTITIES GIVEN ARE FOR ONE HALF OF THE CAUTION AND WARNING SYSTEM; THE SYSTEM ELECTRONICS (EXCLUDING SENSORS) ARE COMPLETELY REDUNDANT.

***ONE SPARE CHANNEL

****TWO SPARE CHANNELS

Figure 5.31 Caution and Warning Parameter Inputs

Each subunit provided a current limited control voltage that was DC isolated fro the input bus. The control voltages from the two C&W subunits were dioded together to provide one combined control voltage; whereas, the emergency subunits control voltages remained isolated. These voltages were routed to their respective C&W System parameter closures and control switches for operating the C&W System. The control voltage returns for all subunits were isolated from each other and all other vehicle returns.

The C&W unit was coldplate mounted on AM Electronics Module 5. In the standby mode, the unit consumed a maximum of 100 watts of power.

(d) High Level Audio Amplifier. A high level audio amplifier (HLAA) was added to the SWS C&W System to provide caution and warning tones in the event of a failure to the buses powering the speaker intercom assemblies. The HLAA amplified the caution or warning tone from the C&W subunits and applied the tone directly to the speakers in the speaker intercom assemblies. The HLAA contained two amplifiers for redundancy; each amplifier was powered from a normally energized bus and was protected by an independent circuit breaker. The HLAA consumed ten watts of power when in the standby mode and a maximum of 100 watts when amplifying the caution and warning audio signals. The HLAA was coldplate mounted on AM Electronics Module 5.

(e) Signal Conditioning Packages. Two signal conditioning packages (C&W instrumentation packages) were provided for redundancy. The signal conditioning packages conditioned preselected signals from the C&W System sensors and voltage levels from monitored buses. A total of 19 caution and 17 warning parameters were routed into level detectors that were preset to trigger when a designated signal level was exceeded. The level detector turned on a relay driver which provided a relay closure to the C&W System. All level detectors in the signal conditioning packages except the PPO_2 low detectors received their basic power from the C&W signal conditioner converters which supplied $\pm$ 24 VDC regulated voltages to the detectors. Power for the relays and the PPO_2 low detectors were powered directly by the EPS control buses. The signal conditioning packages were coldplate mounted on AM Electronics Module 5. The total level detector power consumption was 3.7 watts per package. In addition, each energized relay required approximately one watt of power.

(f) Signal Conditioner Converters. The DC-DC converters converted the EPS bus voltage into $\pm$ 24 VDC and + 5 VDC regulated voltages. The $\pm$ 24 voltages were used to power the level detectors in the signal conditioning packages and the differential amplifiers in the PPO_2 sensors. The + 5 volts were used to power the EVA suit inlet water temperature sensors and the AM coolant loop temperature sensors. Two signal conditioner converters were utilized for redundancy and were mounted on AM Electronics Module 5. Each converter consumed 11.5 watts of power.

(g) ATM Digital Computer/Workshop Computer Interface Unit (ATM Provided). The ATM digital computer provided the primary computational capability for the ATM pointing control system and the cluster attitude control system. There were redundant ATM digital computers which interfaced with the workshop computer interface unit (WCIU) within the ATM. The WCIU provided the input/output buffering and automatic switchover capability for the two digital computers. Each computer contained sub-routines for determining out-of-tolerance conditions and for setting the discrete output registers in the WCIU. The discrete output registers determined the status of the relays which provided the discrete C&W closures. Each ATM digital computer weighed 100 pounds and dissipated 165 watts. The WCIU dissipated 105 watts.

(h) Control and Display Logic Distributor (ATM Provided). The control and display logic distributor housed the relays which were used to provide the C&W closures in the ATM. The combined C&W control voltages, routed via redundant paths from the ATM/AM interface to the C&D logic distributor, were applied to two control buses within the distributor. These control buses provided the C&W control voltage for the various C&W closures. The unit accepted discrete inputs for energizing the various relays and provided redundant outputs which were routed across the ATM/AM interface through separate connectors. The control and display logic distributor dissipated 40 watts of power.

(i) Speaker Intercom Assemblies. Thirteen speaker intercom assemblies (SIAs) were located through the SWS for intercommunications between the crew and communications with the ground. These assemblies contained a red master alarm status light on each unit and were also used for reproducing the caution and warning tones. The caution tone was a continuous 1 kHz frequency while the warning tone was 1 kHz frequency, modulated at a 1.4 Hz rate. The C&W tones were routed to both the SIA speaker and the crewman communication umbilical connectors. In the active mode each SIA consumed 4.0 watts of power. Two flight spares were stored in the OWS for inflight replacement.

(j) Klaxon Assemblies. The klaxon assemblies contained redundant speakers which converted the emergency signals into audio tones. The emergency audio tones were coded to permit the crew to readily identify the nature of the emergency situation. The fire tone was a siren while the rapid delta P tone was a buzzer. For isolation purposes, one speaker in each klaxon assembly was driven by Emergency Subunit 1; whereas, the second speaker was driven by Subunit 2. One klaxon assembly was located in the forward tunnel of the AM and the other in the forward compartment of the OWS.

(k) Sensors. Two sensors, i.e., fire and rapid delta P, were unique to the SWS C&W System. A description of these sensors follows. The remaining sensors used by the C&W System were previously developed.

1 Fire Sensor Assembly. Detection of fire conditions aboard the SWS was accomplished by twenty-two fire sensor assemblies (FSAs) located throughout the pressurized compartments. The fire sensor assembly consisted of an ultraviolet (UV) fire detector and a quick release adapter plate which provided for easy installation and replacement. There were two FSAs located in the MDA, eight FSAs located in the STS, and twelve FSAs located in the OWS. The FSAs located in the MDA and OWS were used to provide general area coverage, whereas, those in the STS were used for viewing particular modules. Each fire sensor assembly was a self-contained unit whose operation was controlled by a fire sensor control panel (FSCP). The FSAs were designed with an optical field-of-view of 120 degrees included cone angle. The detectors, though not totally redundant, were mounted in such a manner as to provide as much coverage overlap as possible. A fire detected by any of the FSAs would result in a generation of an emergency alarm by the C&W System. Six FSAs were stored in the OWS for flight replacement.

The detectors monitored the UV emission from flames and provided for the initiation of an emergency alarm when the UV intensity exceeded the detector threshold level. Flames emit large amounts of photons which include the 1800 to 2800 Angstrom wavelength region of the UV fire sensor.

The detector consisted of two UV radiation sensing tubes and the associated electronics for conditioning the signals. A twin tube approach was utilized to preclude false fire alarms with passage of the Skylab through the earth's radiation belts. One sensing tube monitored background particulates incident upon the system while a second tube monitored both the background particulates and ultraviolet radiation. The pulse rate out of each tube was conditioned by the electronics and filtered to obtain a DC voltage proportional to the pulse rate. The difference between the DC voltage representing the UV detector tube and the background tube was a measure of the UV flux emitted from a fire source. An emergency alarm was initiated when the difference in tube outputs exceeded a preselected value. A statistical analysis of the design, based on estimates of radiation levels expected to be encountered in the Skylab orbit, indicated that a threshold of 35 counts/sec and a time constant of one second would preclude more than one false alarm for each 56 day mission. To compensate for the unexpected, the FSAs were designed with a gain adjust having the capability to select a sensitivity setting from 25 to 75 counts/sec. Typical FSA response time to UV input equivalent to a 50 microampere standard flame at a distance of ten feet was less than one second.

The emergency alarm activated by the FSA had two forms. One was switch closure to the fire sensor control panel (FSCP), which in turn initiated a relay closure for the C&W control voltage which activated the C&W unit. The other emergency signal generated by the sensor provided an electrical ground for a display light located on the FSCP. Extinguishment of the fire resulted in the relay opening. The electrical ground output for the display light remained latched on after a fire was sensed and could only be reset by temporarily removing power from the sensor.

Preflight system verification tests of the fire sensor operation were accomplished during ground tests via a UV light source and the panel mounted test switches. In-flight, partial circuitry tests were performed using the FSCP test switch or the C&W system test fire switch on AM Panel 206.

Although an abundance and variety of commercial fire sensors existed, it was found that little had been accomplished toward developing space qualified devices. Devices subject to an intensive study included the following:

Correlation spectrometer (gaseous products).

Ultraviolet and/or infrared sensors (flame).

Temperature sensors (heat).

The ultraviolet radiation detector was selected.

The results of the study indicated that detection of ultraviolet radiation emitted immediately following the ignition of a fire provided better overall sensitivity, response time and coverage than other type flame detectors. In addition, UV was considered the better parameter for detecting flames, primarily from background considerations, i.e., the UV radiation from the sun was determined to be less likely to trigger false alarms than the infrared radiation given off by any hot body onboard the vehicle.

2 Rapid Delta P Sensor. Detection of rapid decompression of the Skylab pressure was performed by redundant rapid pressure loss sensors. Should the cluster pressure have decreased at a rate of 0.1 PSI/minute or greater, an emergency alarm was generated. This particular pressure decay rate was selected in order to permit time for emergency action. Typically, a meteorite puncture of the vehicle or a large rupture of the vehicle would be the cause of a rapid leak rate. The detectors were located behind the teleprinter paper storage container in the STS.

The rapid pressure loss sensors consisted of a variable reluctance pressure transducer and associated electronics. The electronics buffered the absolute pressure transducer signal to the AM telemetry absolute system, differentiated the pressure signal to obtain a rate of pressure change for the telemetry system, and energized a relay to provide contact closures to the emergency control voltages when the pressure decay rate exceeded 0.10 PSI/minute. The trip point could be adjusted prior to installation via a potentiometer located on the side of the sensor. Application of 28 VDC via the delta P test switch on AM Panel 206 activated a self-test mode in the detector which simulated electrically, an excessive pressure loss and allowed verification of all electronics downstream of the pressure transducer. The sensor consumed 5.6 watts of power.

The rapid pressure loss sensor design utilized was selected following an intensive investigation of available sensors. Due to rigid schedule requirements, sensing devices which required limited development effort and methods with similar application were sought. The devices and methods reviewed included:

Detection of high leak rates which exceeded the makeup capability of the cabin pressure regulators using pressure switches.

Detection of pressure changes across a capillary restriction utilizing a los range differential pressure transducer.

Analysis of the sound spectrum associated with escaping gas as a function of orifice size, direction, pressure differential, etc.

Differentiation of the output of an absolute pressure transducer referenced to cabin pressure.

The absolute pressure transducer/differentiator sensing scheme was selected primarily because of its excellent response time and its ability to directly convert rate information from cabin pressure measurements.

(3) Telemetry. Individual discrete parameters were provided from each subunit to enable ground control to distinguish when a caution, warning, fire or rapid delta P alarm had been generated. Analog data associated with each CWU converter voltage output was also provided. These parameters, in conjunction with the selected vehicle systems telemetry parameters in the Instrumentation System, were used to determine system status and to resolve system anomalies.

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6. <u>Cluster Mission Performance.</u> The major difference between the Skylab Electrical Power System (EPS) performance during the Skylab mission and the premission performance predictions resulted when a structural failure during launch caused the loss of one Orbital Workshop (OWS) solar array wing and restricted the remaining wing to a partially deployed position. The loss of power generation capability represented by this failure temporarily restricted the use of the AM EPS. However, after the remaining OWS solar array wing was deployed and the AM maximum Depth-of-Discharge (DOD) constraints were redefined to compensate for the reduced power generation capability, the AM Power Conditioning Groups (PCGs) performed as predicted to achieve all premission goals.

The energy required during initial phases of the mission was supplied by the eight PCG batteries and the 18 ATM Charger/Battery/Regulator/Module (CBRM) batteries. The SL-1 activation sequence required the two Skylab power systems to operate independently until four hours and 40 minutes after launch, when they would normally have been paralleled and begun to share the total Cluster load requirements. Initially the ATM batteries were essentially inert, since all ATM loads were inactive until after the Cluster was inserted into the planned orbit. Therefore, the AM batteries supplied all the Cluster loads required to be operational during the first moments of the Skylab mission.

Proper operation of the PCGs was verified by ground controllers prior to liftoff of the Cluster. Since the total power requirement at this time was only 1600 watts, each AM battery had a discharge current of 5.5 amps. The power required during the launch and insertion phases was that necessary for operation of the AM Coolant Loop and the AM Telemetry System required for Cluster systems monitoring. The initial activation sequences were performed by the Instrument Unit (IU) automatic sequences. As these sequences were accomplished, the ATM solar array was deployed, the ATM loads were activated, and the ATM batteries began to perform as intended.

All back-up commands and alternate deployment sequences were initiated in an effort to deploy the OWS arrays, but when it became apparent that OWS array deployment was not possible, the Flight Control Team began alternate plans of operation to protect the integrity of both the AM and ATM power systems.

Since the AM PCG batteries could not be recharged without the OWS solar array it was necessary to terminate the battery discharge before permanent damage was done. However, the total cluster load at this time was only 2300 watts, allowing the ATM CBRMs to supply the entire load without exceeding the 30 percent DOD limitation required to achieve a cycle life from the batteries sufficient to support the eight month mission.

While assessment of the integrity of the vehicle was taking place, power management techniques were initiated to minimize the total Cluster load. The most significant techniques used initially were: 1) delayed spinup of the ATM Control Moment Gyros. Control of the vehicle remained by the OWS Thruster Attitude Control System (TACS) which required only momentary power when the thrusters fired and therefore the power requirement for this control mode was considered negligible; 2) delayed activation of the OWS Radiant Heaters. The activation of these heaters was designed to bring the internal temperature of the OWS within the limits required for crew entry. Since it was apparent that the crew would not be launched per the premission schedule, this event could be delayed without compromising the mission. The activation of these heaters was never accomplished during the Skylab mission because the OWS internal temperatures never again dropped below the lower limit of the crew comfort requirements; and 3) the MDA Wall Heater Thermostats were not reset to their 70°F setting as planned. Similar to the OWS Radiant Heaters, this change in set-point was designed to allow shirtsleeve entry of the crew into the Cluster. With the launch of the manned spacecraft delayed, this set-point adjustment could be delayed without compromising vehicle integrity as long as the internal MDA and AM temperatures were monitored to insure that the coolant loops were above the minimum temperature requirements.

During the launch delay several substitute designs evolved to replace the meteoroid shields function of shading the OWS skin from the Sun's direct rays. Immediately upon insertion, the direct rays of the Sun on the exposed OWS skin created such a severe hot environment inside the OWS that food supplies and film in the storage lockers approached their maximum temperature limits. In an attempt to cool the OWS and prevent loss of the planned manned mission due to food spoilage and film deterioration, the vehicle was maneuvered out of the normal solar inertial pointing mode into an orientation resulting in less direct sunlight on the OWS exposed skin. The departure from the SI pointing mode resulted in a reduced ATM solar array output capability, and the use of power management techniques was mandatory to maintain the integrity of the ATM power system.

Table 6.I summarizes the off nominal pointing modes which were implemented during this first unmanned storage phase in an attempt to protect the integrity of all Cluster subsystems. Frequent changes in the vehicle attitude were required because no single attitude was optimum for all vehicle subsystems. The ideal attitude for the OWS environmental problems caused the AM coolant loop to approach freezing; the attitude required to thaw the AM coolant loop reduced the solar array output to an unacceptable level; etc. Therefore, it was necessary for the ground controllers to continuously monitor all systems and vary the attitude to insure integrity of the vehicle.

NO OF CBRMs	β = 0, SI CAPABILITY	INCIDENT ANGLE	COSINE X 100%	ATM SYSTEM CAPABILITY
18	4800	0°	100.0	4800
18	4800	35°	81.9	3931
18	4800	45°	70.7	3394
18	4800	55°	57.4	2755
18	4800	60°	50.0	2400
17	4540	0°	100.0	4540
17	4540	35°	81.9	3718
17	4540	45°	70.7	3210
17	4540	55°	57.4	2606
17	4540	60°	50.0	2270

Table 6.I. CBRM "Energy Balance" Off-Nominal Capability

During the off-nominal pointing modes, it was decided that the Cluster load requirement made necessary a revision to the mission rule which required that an average CBRM battery DOD of 30 percent be maintained. The MSFC/JSC management decision was to allow the batteries to operate within energy balance each orbit, that is, the only constraint on battery operation was that the battery "Recharge Complete" indication was present for each of the CBRM batteries prior to entering each orbital night. The revised criteria increased the ATM power system total output capability 300 watts to the levels shown in Table 6.I.

The premission predicted load profile indicated an average load for the first unmanned period of 4500 watts. As long as the vehicle remained in SI the ATM power system had sufficient capability to provide the total power requirement without off-loading. However, as the Sun incident angle increased to greater than 30 degrees power management techniques were required. A list of candidate off-loads was generated; this list served as a shopping list of load reduction possibilities to be used as necessary to reduce the total Cluster load requirement within the capabilities of the ATM power system. Table 6.II is the list of candidate off-loads used by the ground controllers during the crucial unmanned period.

LOAD TITLE	TOTAL CONNECTED LOAD-WATTS
AM WALL HEATERS (15)	216.0
MDA WALL HEATERS (8)	546.6
CSM PORT ASSEMBLY HEATER	19.9
CSM TUNNEL HEATERS (2)	185.6
SPARE DOCKING PORT HEATER	19.9
AM COOLANT PUMP (1 OF 6)	85.0
AM TM TRANSMITTERS (10 WATT) (3)	138.6
ATM TM TRANSMITTERS (2)	117.6
ATM VALVE ELECTRONICS CONTROL ASSEMBLY	20.0
ATM TCS MONITOR	2.0
ATM PUMP INVERTER ASSEMBLY	125.0

Table 6.II. Unmanned Off-Load Candidates

On DAY 10, in an attempt to solve the pressing thermal problems, the vehicle was maneuvered to an attitude resulting in a Sun incident angle of 55° for an extended period. As seen in Table 6.I, the ATM power system capability at this attitude was only 2755 watts. The available off-loading did not permit reduction of the total Cluster load within this value and the constraint to operate the system within energy balance was waived. More energy was taken out of the batteries during the night portion of the orbit than could be replaced during the sunlight portion. Vehicle attitude was not constrained to allow the batteries to recharge. A CBRM design feature automatically disconnected each CBRM from the load buses when the battery voltage approached 26.4 volts. Continued operation at this attitude resulted in a depletion of the CBRM battery stored energy, and eight batteries auto-disconnected from the load buses leaving the ten remaining CBRMs to supply the entire load. The Sun incident angle was then decreased and seven of the CBRMs were reconnected to the buses during orbital daylight. CBRM 15 failed to respond to the attempts to reconnect it to the load buses. Analysis of this anomaly concluded that the CBRM 15 solar array contactor was failed open. The loss of this CBRM resulted in a reduction in the ATM power system capability to the values shown for the 17 CBRM configuration in Table 6.I.

During this unmanned phase, the total cluster capability varied from 4800 watts average per orbit in the SI mode with 18 CBRMs, to 2270 watts at the 60 degree pitch attitude with 17 CBRMs. The ATM average load for this period was approximately 1600 watts. Since the ATM EPS was providing all the power, the remaining 3200 watts, maximum, was transferred across the ATM/AM interface to the Transfer Buses for distribution to the OWS/AM/MDA loads. The majority of the load for this period was on AM Bus 1 and AM Bus 2 with OWS Bus 1, OWS Bus 2, EPS Bus 1, and EPS Bus 2 having very small loads on-line.

Figure 6.1 shows the average load requirement for the first unmanned period. Since the total load was being controlled to remain within the maximum system capability, the load profile as depicted approached the power system capability average over the 24 hour periods that are plotted. Figures 6.2 and 6.3 are a breakdown of the load requirements for DAY 7 which was a typical day in the "Launch to Activation" phase. Table 6.III describes the bus voltages for DAY 7; the voltage levels for this time period are substantially above the 24-volt minimum bus voltage required to be delivered to the components.

Although rigorous power management techniques were required for the entire time period, the ATM EPS capability was sufficient to supply the load requirements for the vehicle attitude dictated, and to protect the integrity of each subsystem. The loss of CBRM 15 due to excessive discharge, causing solar array contactor opening during this time period, was the only power system anomaly that resulted in a continuous degradation of the power system output capability.

BUS	MINIMUM VOLTAGE (VOLTS)	MAXIMUM VOLTAGE (VOLTS)
ATM MAIN 1 and MAIN 2	28.69	28.97
XFER 1 and 2	28.43	28.90
AM 1 and 2	28.42	28.83
EPS 1 and 2	27.64	28.67
OWS 1 and 2	28.22	28.64

Table 6.III. Bus Voltages DAY 7

After crew installation of the OWS parasol heat sheild, the SWS was returned to the solar inertial attitude where it remained, except for occasional excursions to the Z-LV attitude for EREP operations.

For the first 14 days of the planned 28 day manned mission the ATM EPS continued to supply the total SWS power requirement. Since the CSM power was being supplied by the CSM fuel cells it was not necessary for the ATM EPS to supply any power to the CSM. The average load

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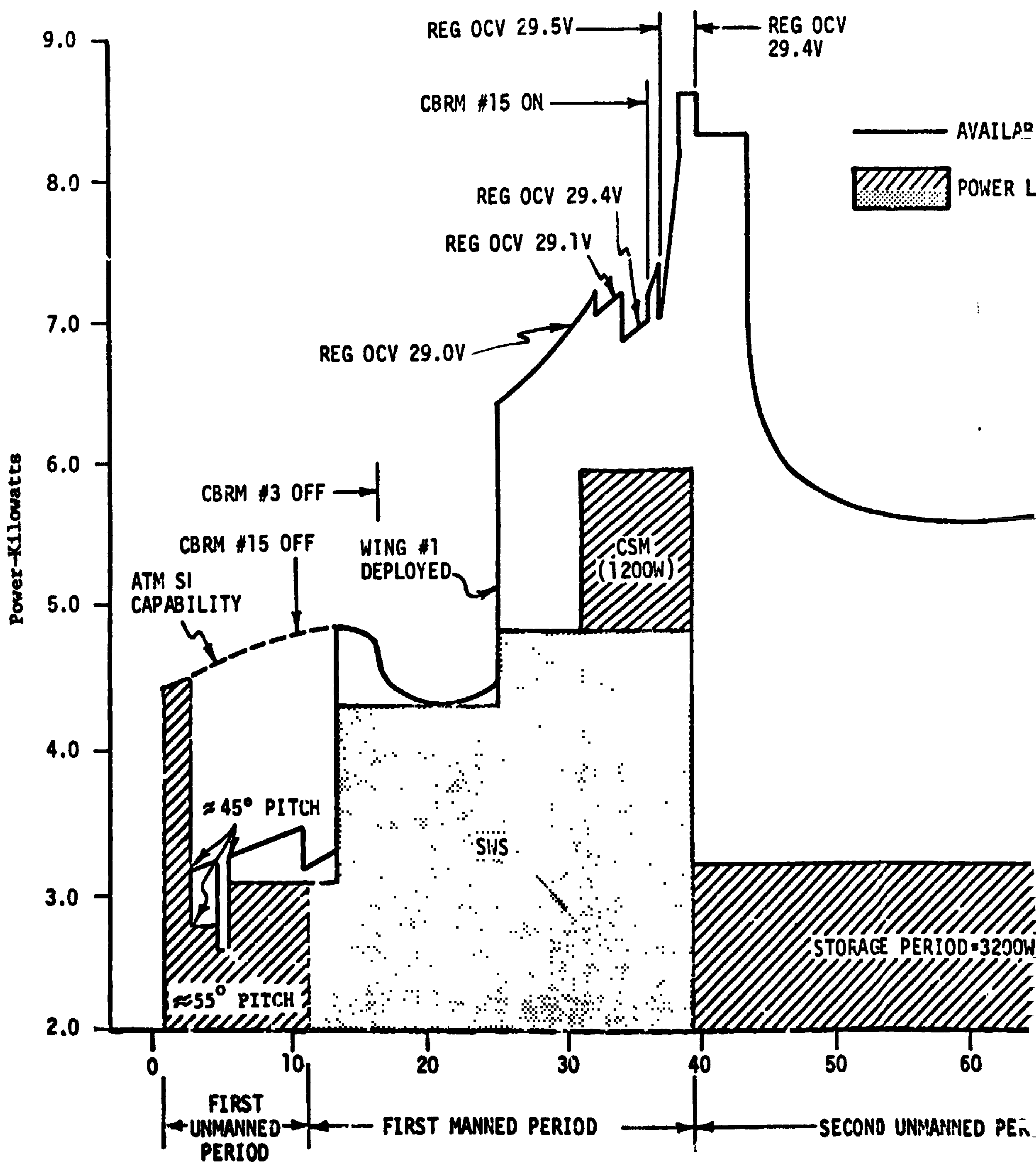

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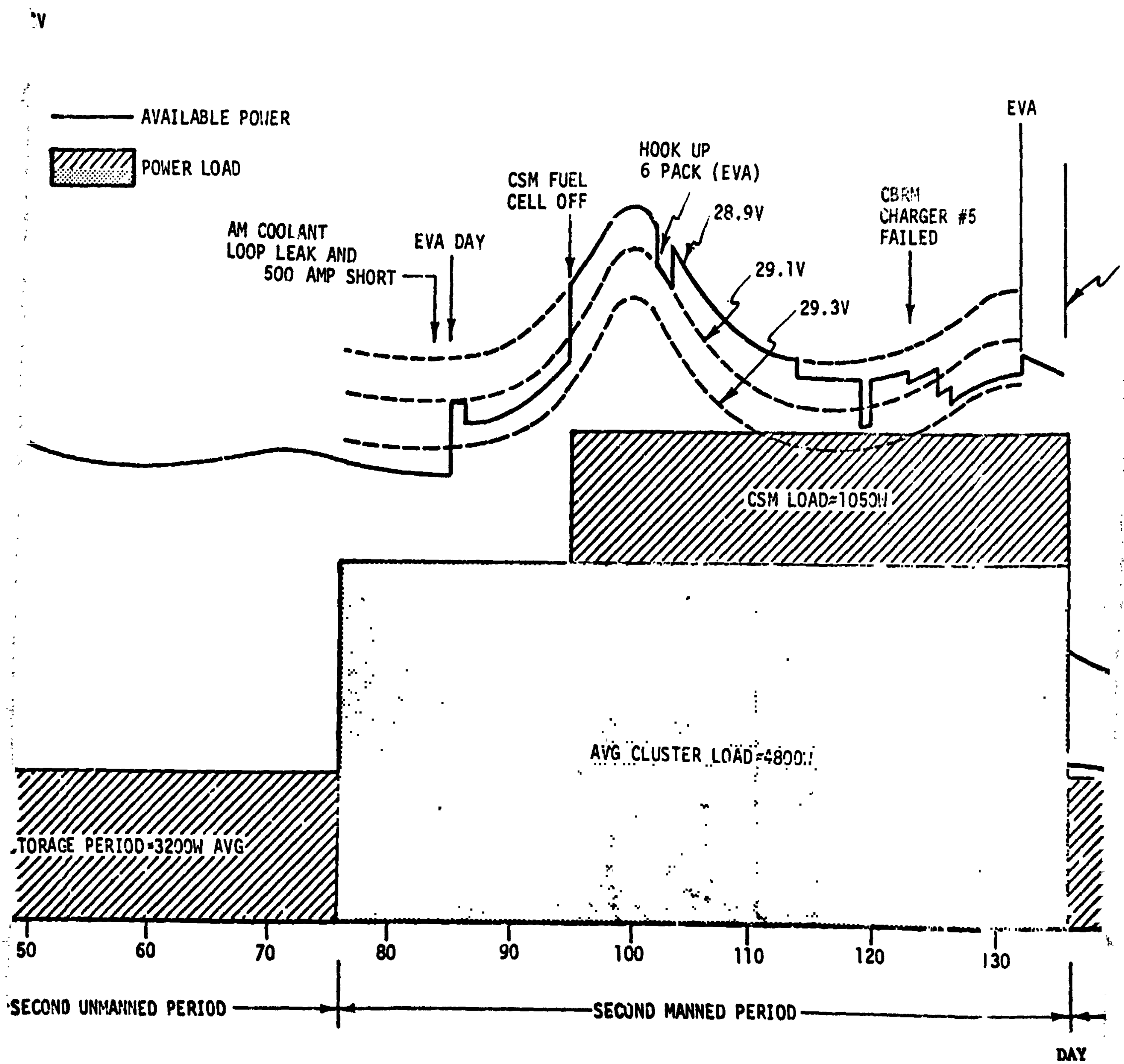

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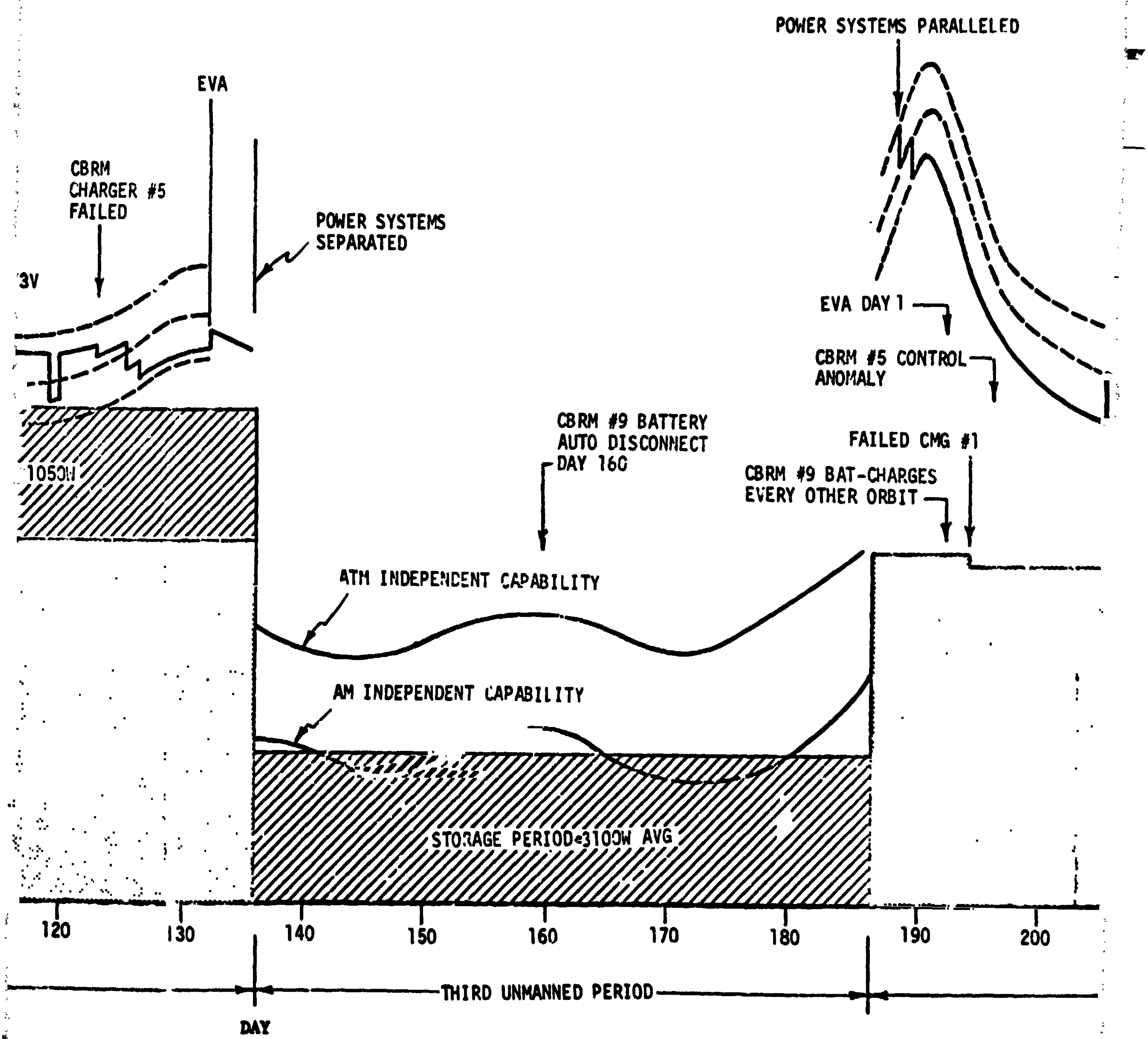
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EVA
CBRM
CHARGER #5
FAILED
POWER SYSTEMS
SEPARATED
3V
EVA DAY 1
CBRM #5 CONTROL
ANOMALY
CBRM #9 BATTERY
AUTO DISCONNECT
DAY 160
FAILED CMG #1
CBRM #9 BAT-CHARGES
EVERY OTHER ORBIT
1050W
ATM INDEPENDENT CAPABILITY
AM INDEPENDENT CAPABILITY
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120
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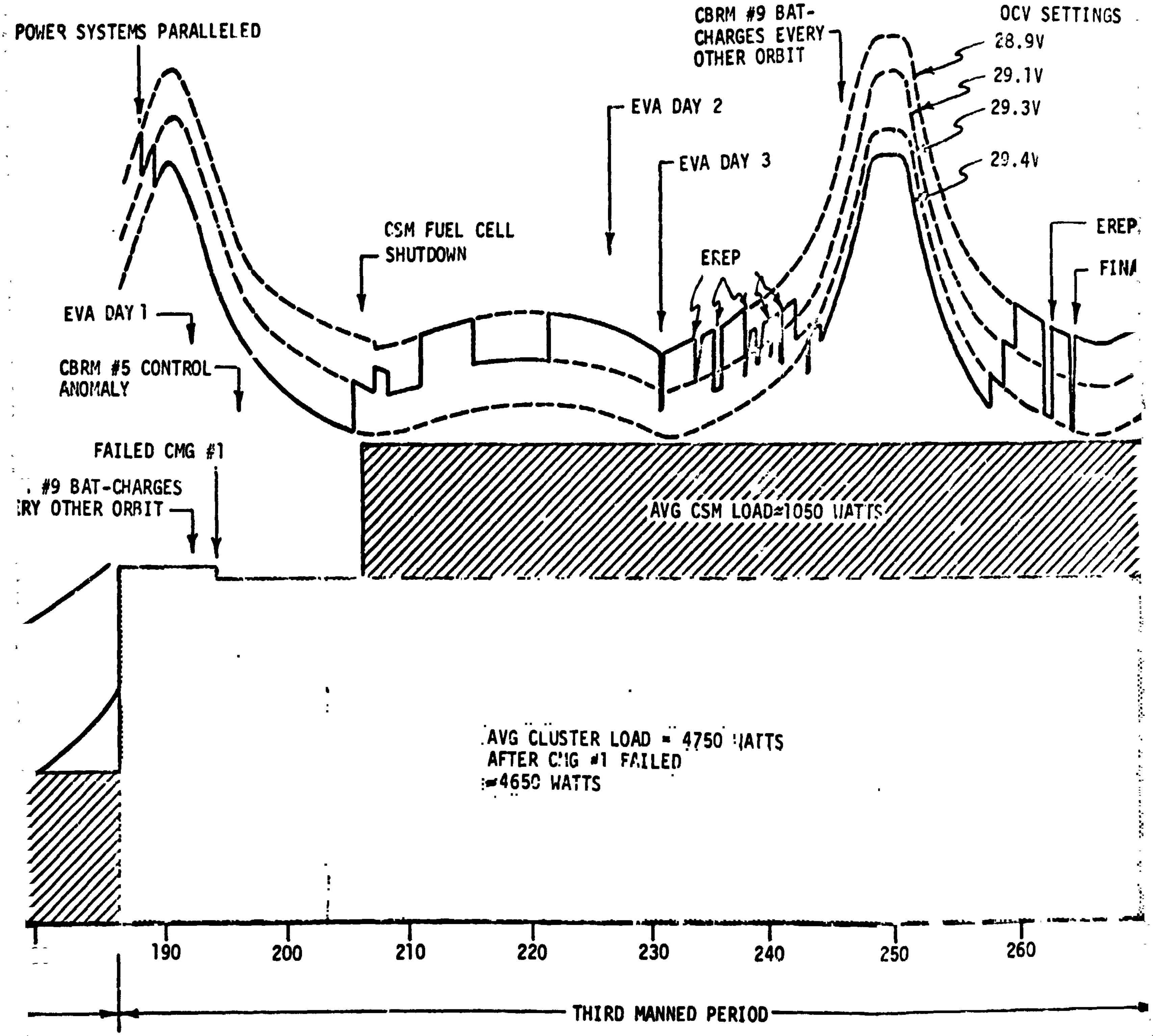

Figure 6.1 Skylab EPS Capability/Load

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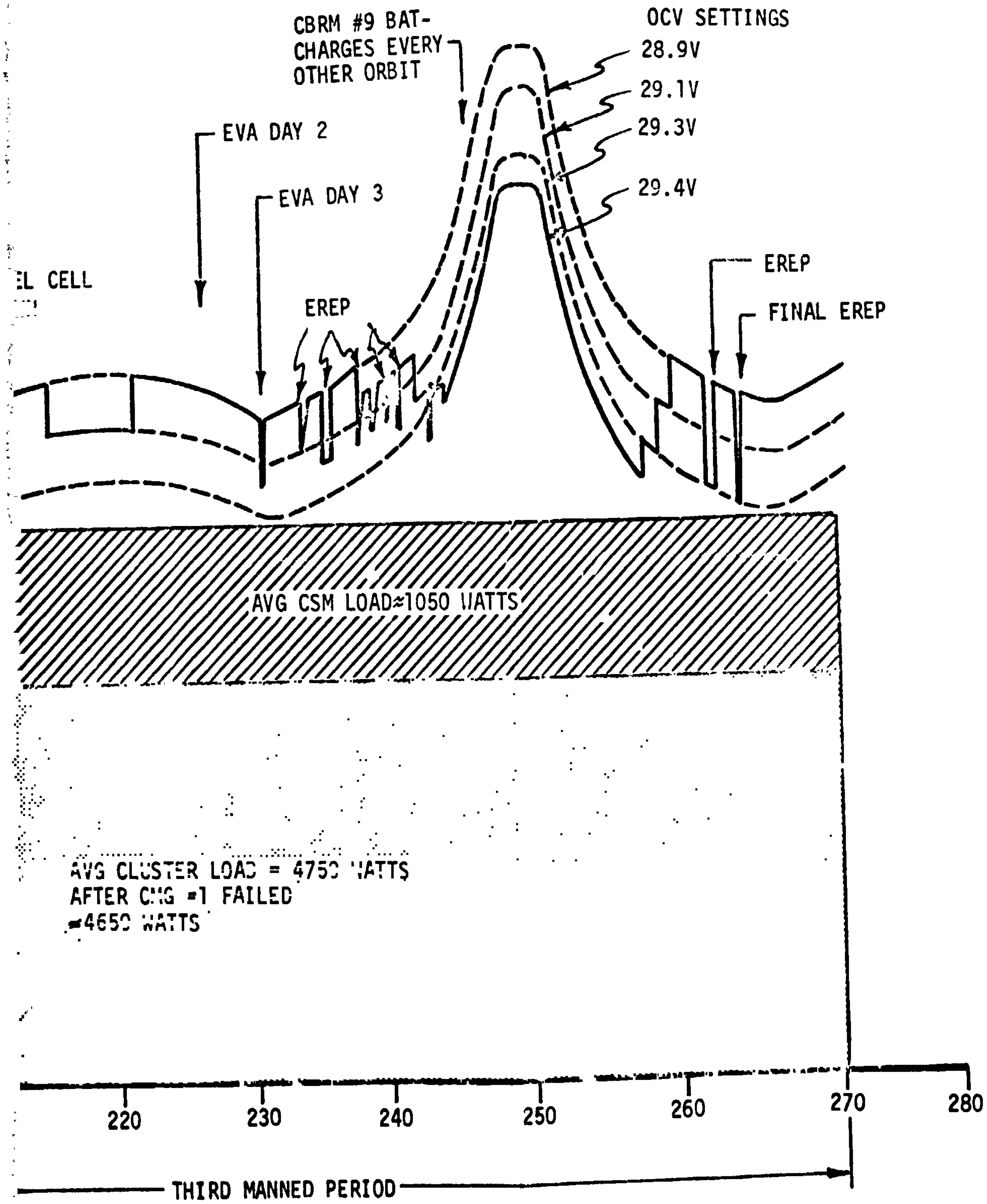

Figure 6.1 Skylab EPS Capability/Load History

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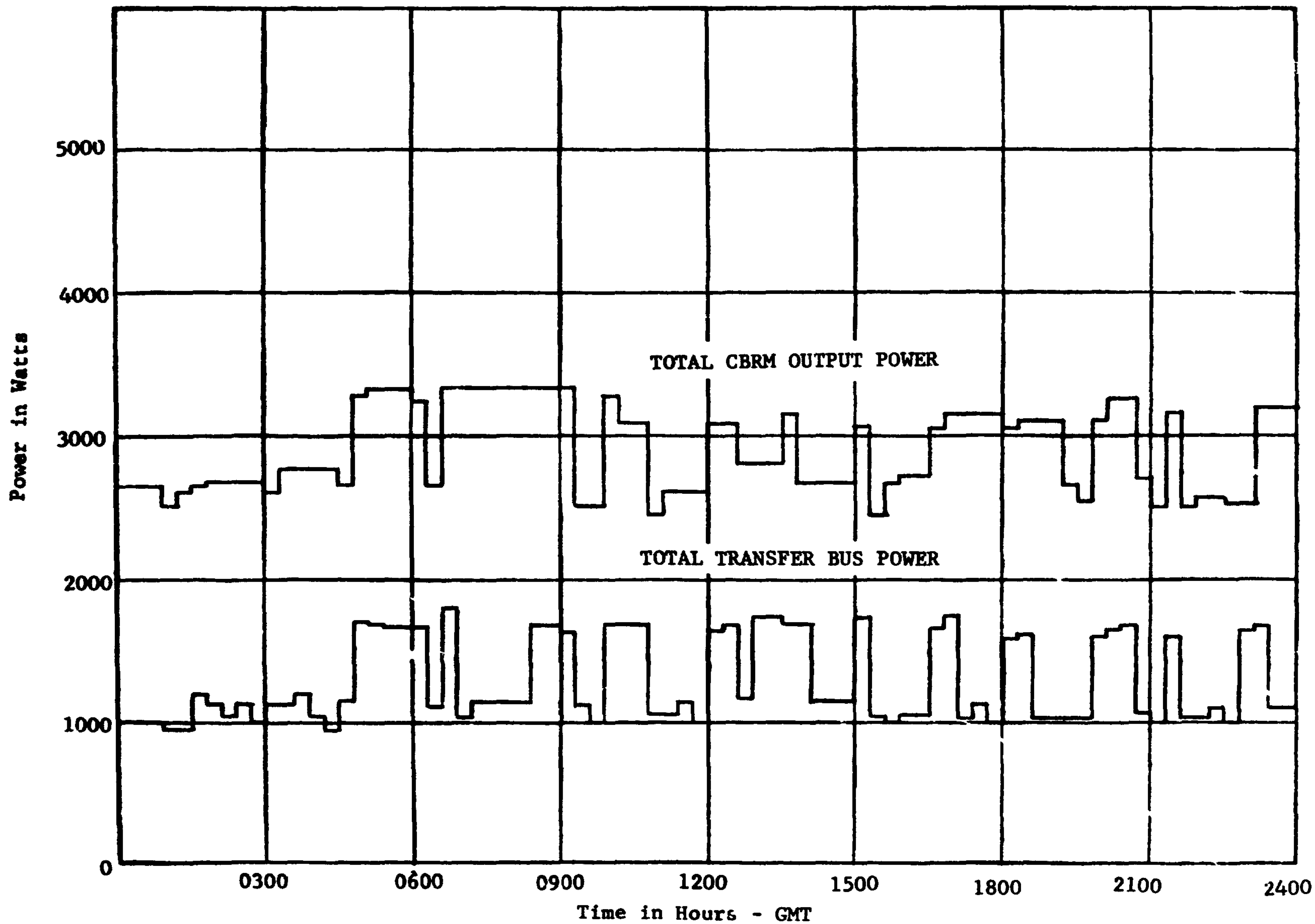

Figure 6.2 SWS Power Requirements and Power Transfer For DAY 7

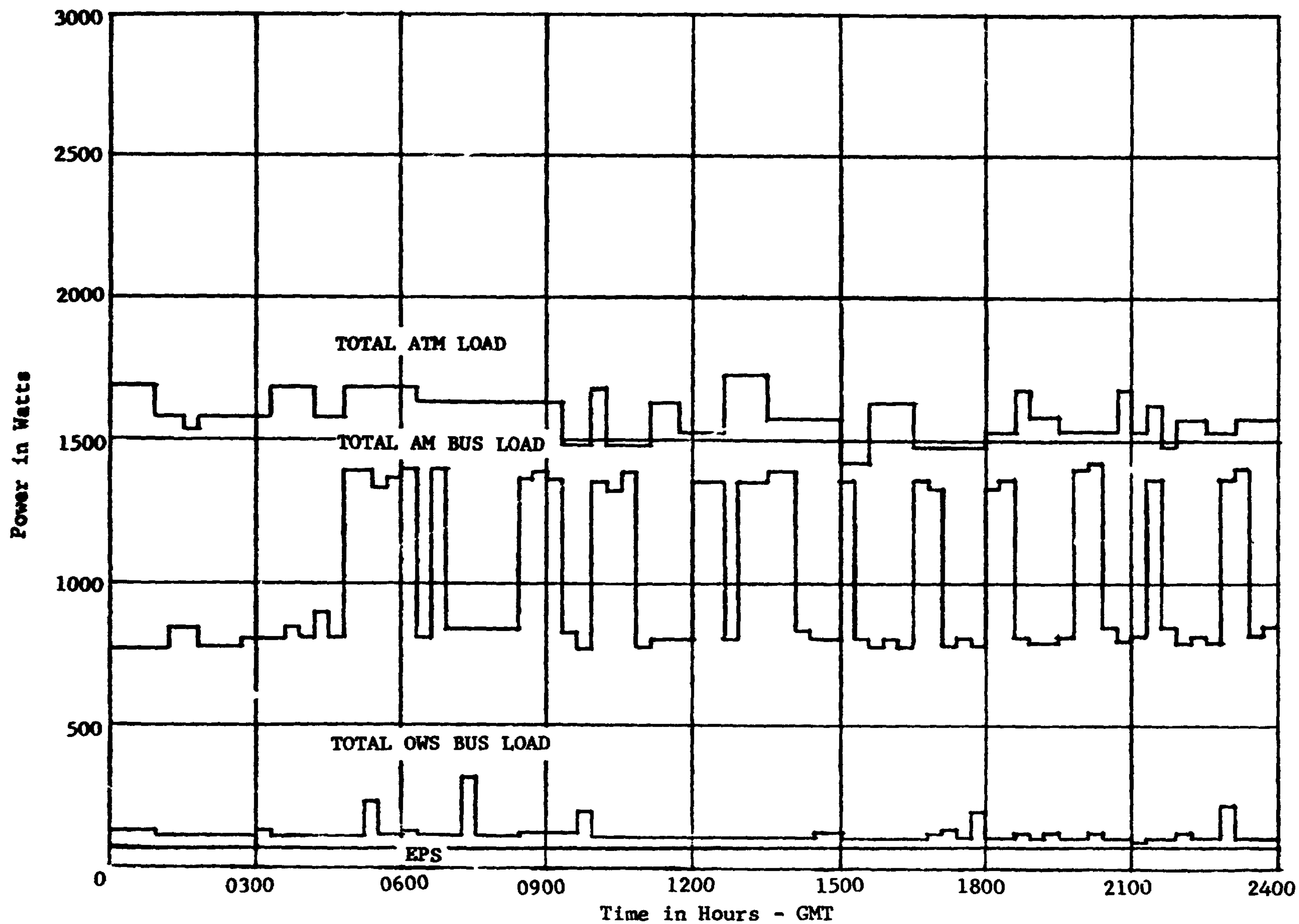

Figure 6.3 Bus Power Requirement for DAY 7

requirement for the first 14 days of the manned mission can be seen in Figure 6.1. Extensive load management was required during this period to ensure that the load requirement did not exceed the capability of the system.

On DAY 17, during EREP 1, the ATM batteries were excessively discharged due to the long pass duration and the high loads. As a result, CBRMs 6, 7, 8 and 16 automatically disconnected from the ATM load buses. Following return to solar inertial and acquisition of sunlight, these CBRMs were reconnected to the load buses. Soon after acquisition of sunlight, CBRM 3 automatically disconnected from the load buses. CBRM 3 did not respond to the commands to reconnect it to the buses and subsequent analyses revealed that the CBRM 3 regulator had failed. CBRM 3 was lost for the remainder of the Skylab mission and the total remaining at this time was 16 of the original 18 CBRMs. Additional degradation was observed on DAY 24 when CBRM 17 output exhibited a reduced power output during specific orbital periods. The estimated loss of capability was 80 percent of the CBRM 17 capability or approximately 150 watts left in the average ATM system capability. Subsequent review of data indicated that this anomaly occurred on DAY 11.

To avoid further degradation in the ATM power system output capability due to excessive discharge, the system power management procedures were updated and each flight plan activity was carefully analyzed. The critical periods continued to be during EREP passes when the vehicle was maneuvered to the Z-LV attitude for experiment pointing. Four additional EREP passes were completed during the six mission days following EREP 1. The most significant power management technique used for these four passes was to shorten the total time out of the solar inertial attitude. EREP 1 had an experiment data-take period of 127 orbital degrees or approximately 33 minutes. The maximum data-take for the next four EREPs was 46 degrees or 12 minutes for EREPs 4 and 5 on DAYs 22 and 23 respectively. Table 6.IV summarizes the pass geometry, pass duration, and total cluster load for the first five EREP passes of the SL-1/SL-2 mission.

The maximum total cluster load requirement for the first five EREP passes occurred during EREP 1. The EREP instruments each require peak power during the data take period. During this period the power transfer from the ATM power system to the AM Transfer Buses exceeded 3200 watts. Although 3200 watts is in excess of the 2500 watt maximum transfer used as a design goal for sizing the transfer network, all systems performed without degradation. Figure 6.4 and 6.5 are a breakdown of the load requirements for DAY 17 which included EREP 1; Table 6.V shows the maximum and minimum bus voltages for the EREP period. Although the total power transfer exceeded the premission maximum criteria, it can be seen from Table 6.V that the system voltages remained above the levels required to insure a minimum of 24 volts to the component.

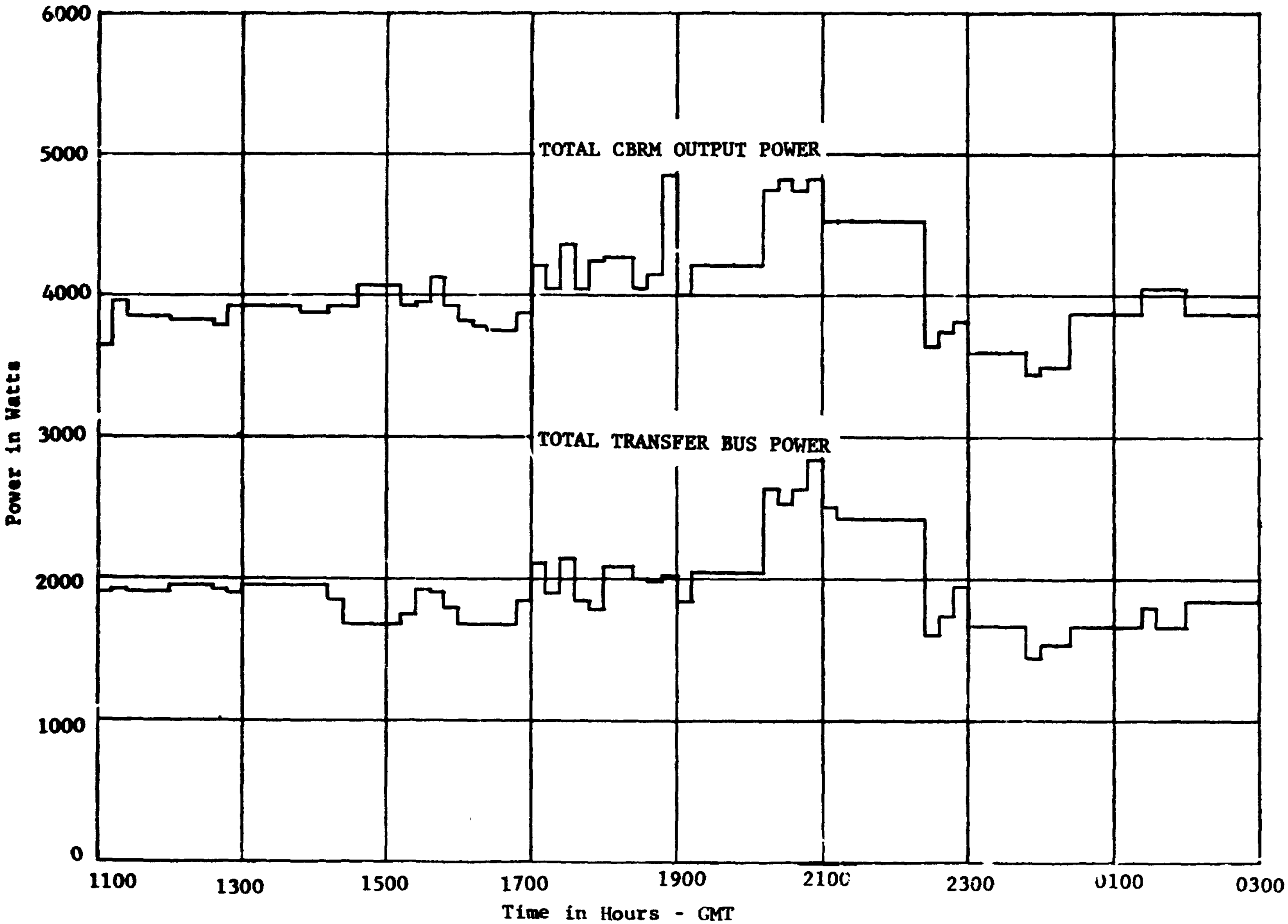

Figure 6.4 CBRM, and Transfer Bus Power for DAY 17

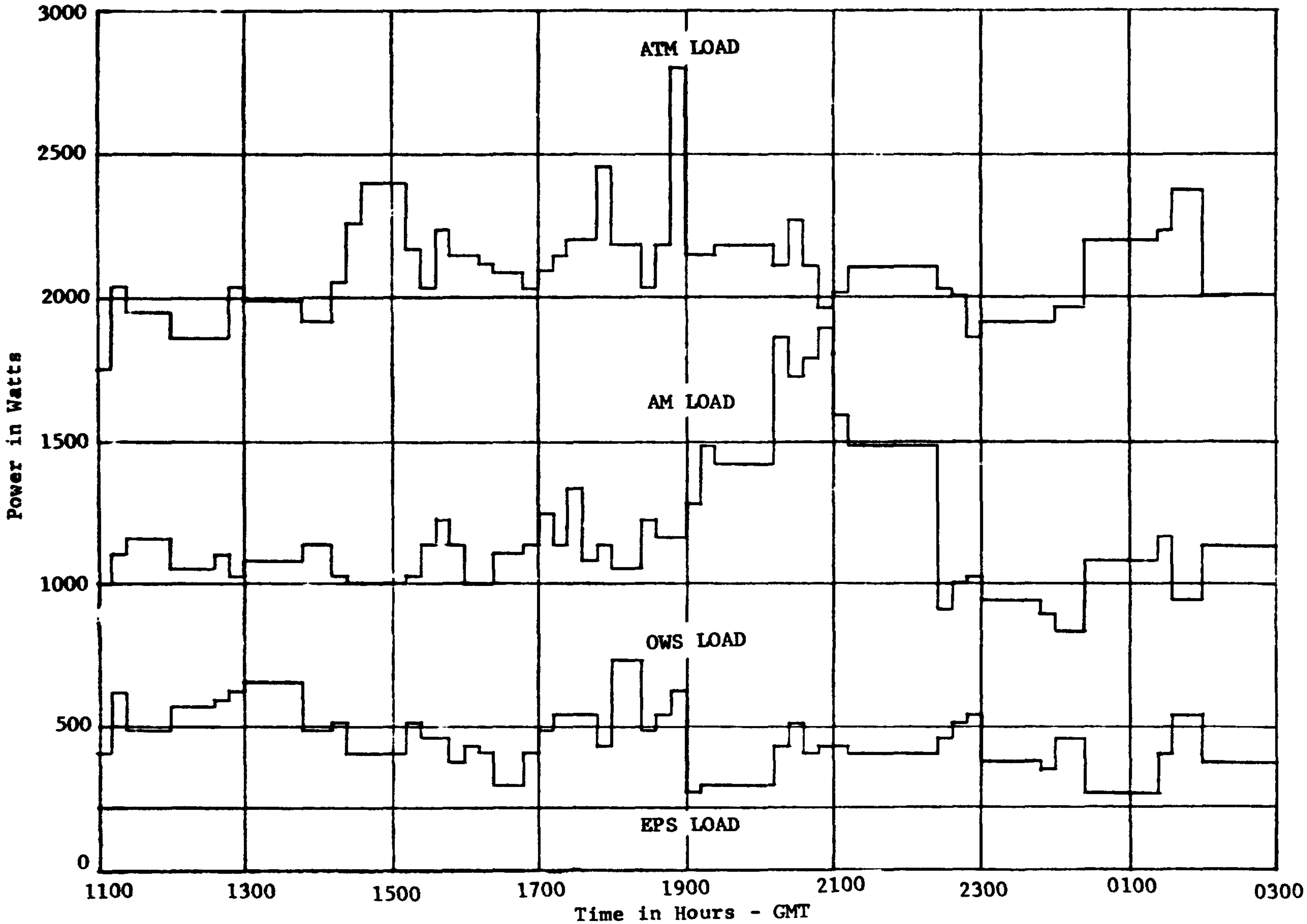

Figure 6.5 Bus Power Requirements For DAY 17

EVENT	PASS #1 DAY 17 (DEG)	PASS #2 DAY 20 (DEG)	PASS #3 DAY 21 (DEG)	PASS #4 DAY 22 (DEG)	PASS #5 DAY 23 (DEG)
ORBITAL MIDNIGHT	0	0	0	0	0
START MANEUVER TO Z-LV	106	141	139	116	120
END MANEUVER TO Z-LV	141	160	158	147	150
START DATA TAKE	156	160	158	147	150
ORBITAL NOON	180	180	180	180	180
END DATA TAKE	260	199	201	193	196
START MANEUVER TO SI	268	199	201	193	196
END MANEUVER TO SI	338	218	220	213	216
TOTAL DURATION OF Z-LV	127	39	43	46	46
TOTAL DATA TAKE DURATION	104	39	43	46	46
ORBITAL AVERAGE LOAD	4550 WATTS	4000 WATTS	4030 WATTS	3950 WATTS	3970 WATTS

Table 6.IV. EREP Pass Geometry - First Five Passes

During the solar inertial pointing mode the total cluster load requirement was managed to insure that the ATM power system capability was not exceeded. The premission predicted load for this time period of 5500 watts revealed a need to reduce the total load by 1000 to 1500 watts to remain below the ATM system capability. Approximately 500 watts of the premission prediction was power required by the OWS duct heaters. When the meteoroid shield was destroyed during launch subjecting the OWS skin to direct sunlight, the OWS internal environment exceeded the premission predicted temperatures, and the OWS duct heaters were never required during the entire Skylab Manned missions. An additional 200 watts of the premission prediction appeared to be conservatism in the component load requirements. Thus, if the cluster operation was continued to the premission plans a total load of 4800 watts would have resulted. Since this exceeded the ATM system output capability power management techniques were used to further reduce the load. The primary loads which were managed to facilitate this load reduction were the MDA and AM Wall Heaters, Internal Cluster Lights, the redundant C&W components, Cluster fans and the AM Molecular Sieve. To implement management of these loads required crew participation as well as the continued management by the electrical ground controllers.

BUS	MINIMUM VOLTAGE (VOLTS)	MAXIMUM VOLTAGE (VOLTS)
ATM MAIN 1 and MAIN 2	28.38	28.56
TRANSFER 1 and 2	27.79	28.03
AM 1 and 2	27.55	27.96
EPS 1 and 2	26.85	27.17
OWS 1 and 2	27.25	27.67

Table 6.V. Bus Voltages DAY 17

Although the power management techniques had to be constantly applied and the results monitored, it was possible to continue all planned astronaut tasks with the limited power available. Therefore, the implementation of the power management techniques did not compromise the planned mission objective, nor did they cause undue complications in the flight planning of desired astronaut tasks and experiments.

On DAY 25 the SL-2 astronauts diligently executed a repair procedure developed by the back-up crew in the Zero-G simulator and OWS Solar Wing 1 was freed from the metal restraining it and subsequently deployed to its normal position. The resulting increase in the total power system capability heralded the end of the rigorous power management techniques and a return to the premission plans for the spacecraft systems operations. For the remaining 14 days of the SL-2 mission all solar inertial mode orbits had a positive power margin of at least 800 watts. Power management techniques were required to accomplish the six EREP passes following wing deployment due to the increased length of maneuvers and data take durations. Table 6.VI shows the geometry for each of the last six SL-2 EREP passes together with the average load requirement and the battery Depth of Discharge (DOD).

EVENT	PASS #6 DAY 27	PASS #7 DAY 28	PASS #8 DAY 29	PASS #9 DAY 30	PASS #10 DAY 31	PASS #11 DAY 32
ORBITAL MIDNIGHT	0°	0°	0°	0°	0°	0°
START MANEUVER TO Z-LV	61°	15°	51°	35°	29°	57°
END MANEUVER TO Z-LV	115°	111°	109°	97°	106°	115°
START DATA TAKE	115°	111°	117°	112°	106°	115°
ORBITAL NOON	180°	180°	180°	180°	180°	180°
END DATA TAKE	216°	216°	225°	205°	214°	227°
START MANEUVER TO SI	216°	216°	225°	205°	214°	227°
END MANEUVER TO SI	247°	254°	267°	235°	253°	273°
TOTAL DURATION OF Z-LV	101°	105°	116°	108°	108°	112°
TOTAL DATA TAKE DURATION	101°	105°	108°	83°	108°	112°
ORBITAL AVG LOAD	4800	5300	5360	5100	5350	5350
PCG MAX BATTERY DOD	NO DATA	25.0%	28.5%	31.0%	32.0%	40.0%
CBRM MAX BATT DOD	NO DATA	35.0%	30.2%	26.0%	24.5%	32.1%

Table 6.VI. EREP Pass Geometry-Passes 6 through 11

Once the OWS Solar Array was deployed and the PCGs were reactivated, the ATM and AM power systems operated in parallel to share the total cluster load requirement. The power sharing between the ATM and the AM EPS was controlled by adjusting the open circuit voltage (OCV) of the AM/OWS EPS. This adjustment was controlled by the astronauts by turning the onboard potentiometer to the desired setting. The adjustment was not available to the ground controllers.

The goal of the original OCV setting was to maintain an average maximum DOD on the CBRM batteries of 30 percent and 15 percent on the PCG batteries. The lower DOD on the PCGs was imposed by the loss of one-half of the OWS solar array. To achieve the desired sharing of the ATM and AM EPSs to ensure these DOD constraints would not be violated, an OCV of 29.0 volts was selected, as the original value. Once the constraints and the OCV were selected, the total capability defined by these constraints was identified. The capability for this setting was adequate to supply the total load requirements with an approximate 500 watt positive power margin, as shown by Figure 6.1. Figures 6.6 and 6.7 plot the ATM EPS output, the AM EPS output and the ATM to AM transfer current for the paralleled systems. Figure 6.6 shows a typi-

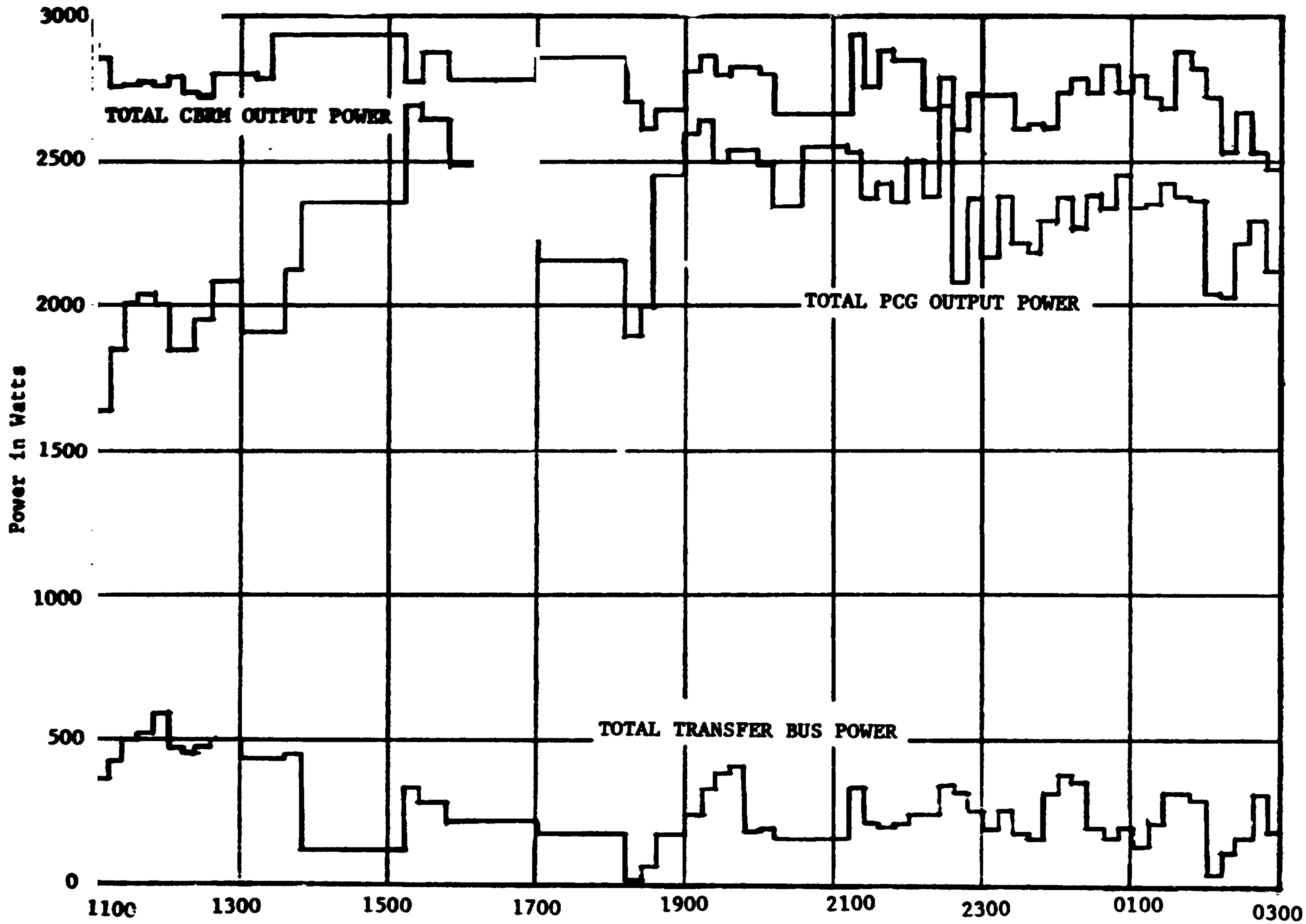

Figure 6.6 CBRM, PCG and Transfer Power For DAY 29

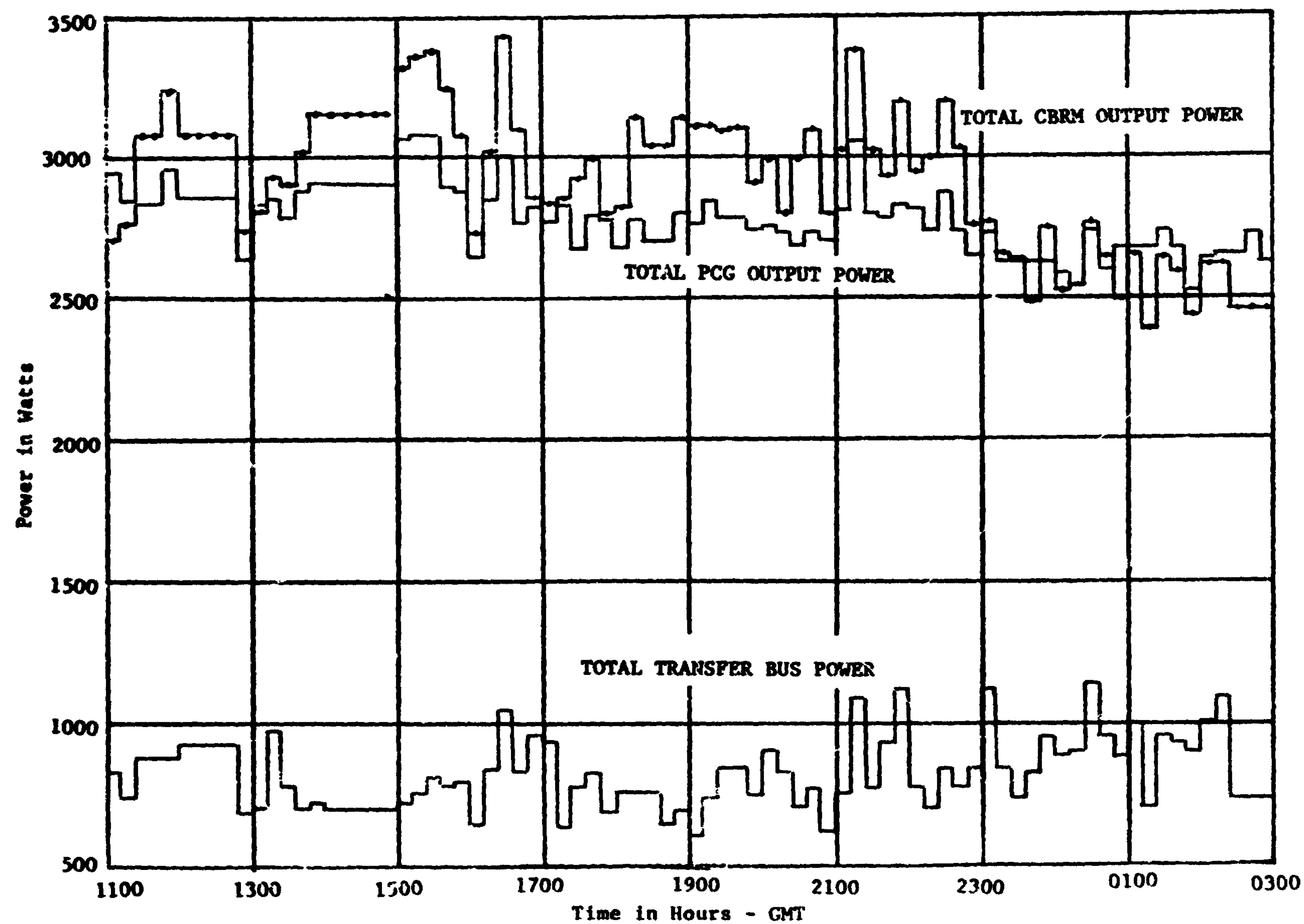

Figure 6.7 CBRM, PCG and Transfer Power For DAY 36

cal day containing an EREP pass prior to the CSM fuel cell shutdown. Figure 6.7 shows a typical day after fuel cell shutdown.

Due to the low DODs on the PCG batteries, compared to the design value of 30 percent, and the availability of additional OWS solar array power, it was decided that 15 percent DOD limit on the PCG batteries should be relaxed. By operating the PCG batteries at the energy balance point, the DODs on the CBRM could be reduced to optimize the total EPS lifetime. To increase the PCG DOD, the OCV was adjusted to 29.4 volts and the ATM to AM/OWS transfer current was reduced.

On DAY 32, after 21 days of operation, the CSM fuel cells were deactivated, and the SWS EPS began to provide the total CSM power requirement. The CSM average load for the remaining seven day period was approximately 1200 watts with a peak load of 2200 watts average for a two hour period during the CSM Entry Simulations. Figure 6.8 shows the CSM load requirement for DAY 35 which was a typical day after the SWS EPS began to supply CSM power. Figure 6.9 describes the DAY 33 CSM power requirement which was the highest average load day due to the gimbal motor checks during the entry simulations.

The SWS EPS was paralleled briefly with the CSM fuel cells prior to the fuel cell shutdown. The paralleling procedure was accomplished, as written, and the OCV was returned to the original setting per the procedure. During the SWS deactivation, the CM Descent Batteries were paralleled with the SWS EPS during the CSM transfer to internal power. Once more, this procedure was accomplished as planned without evidence of degradation of any EPS parameters.

On DAY 37, during the astronaut EVA to retrieve the ATM experiment film, an astronaut rapped CBRM 15 with a hammer and the ground commands were sent to reconnect CBRM 15 to the load buses. This technique was successful and CBRM 15 began to perform normally. For the remainder of the SL-2 mission and the storage period between the SL-2 and SL-3 missions, 17 CBRMs were active. During deactivation of the SWS for storage, an OCV adjustment to 29.4 volts was made to optimize the load sharing during the orbital storage period.

During the storage period between the SL-2 and SL-3 missions, the Skylab electrical load requirement averaged 3100 watts per orbit. Since the average power system capability exceeded 5500 watts for the entire period, a positive power margin of over 2000 watts existed for the entire storage period. The power system operated normally during the storage period without failure of additional subsystems or off-nominal operations. The 29.4 volt OCV setting served to equalize the load sharing between the AM and ATM EPSs and the transfer current was optimized.

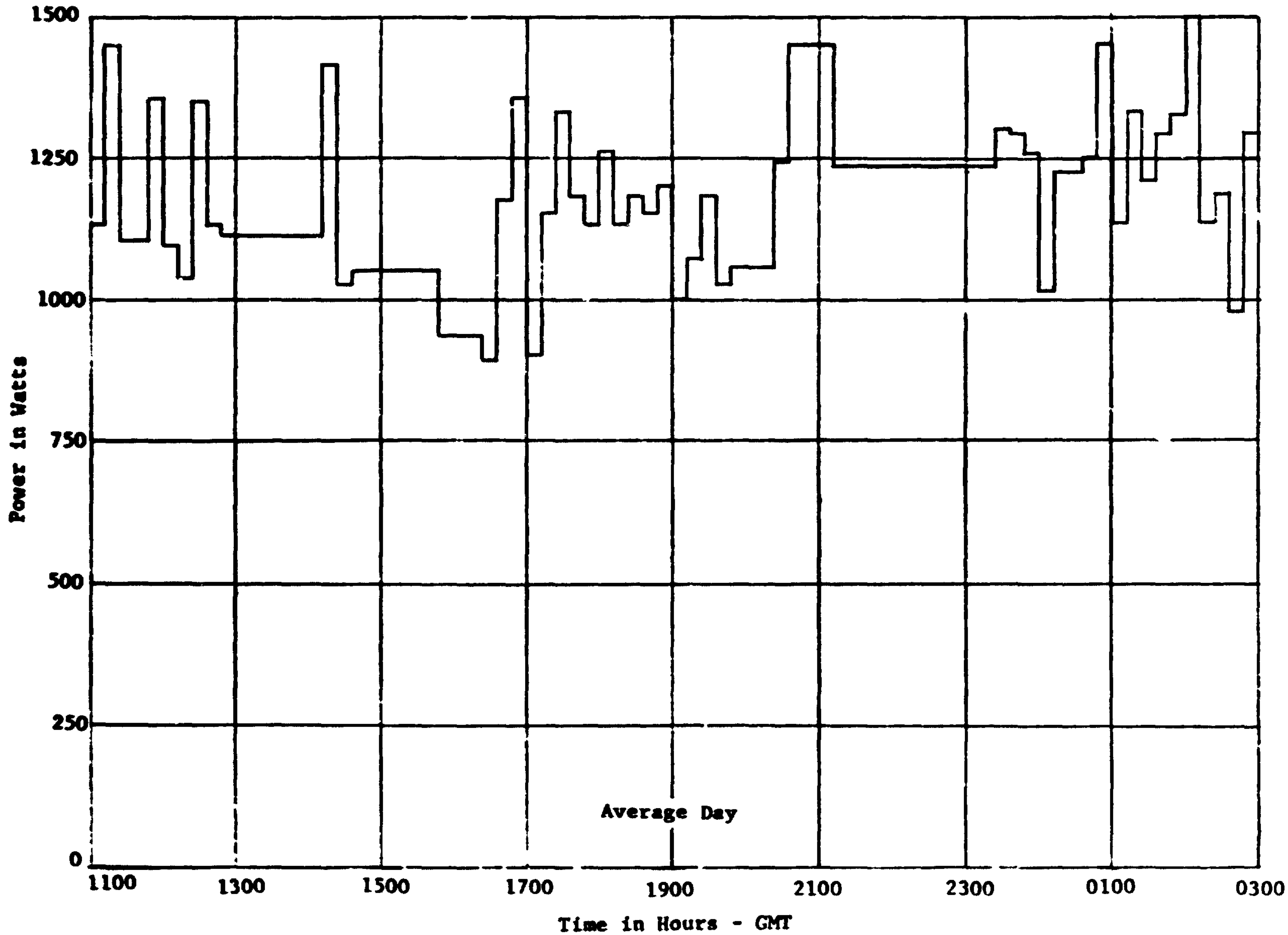

Figure 6.8 CSM Power Transfer for DAY 35

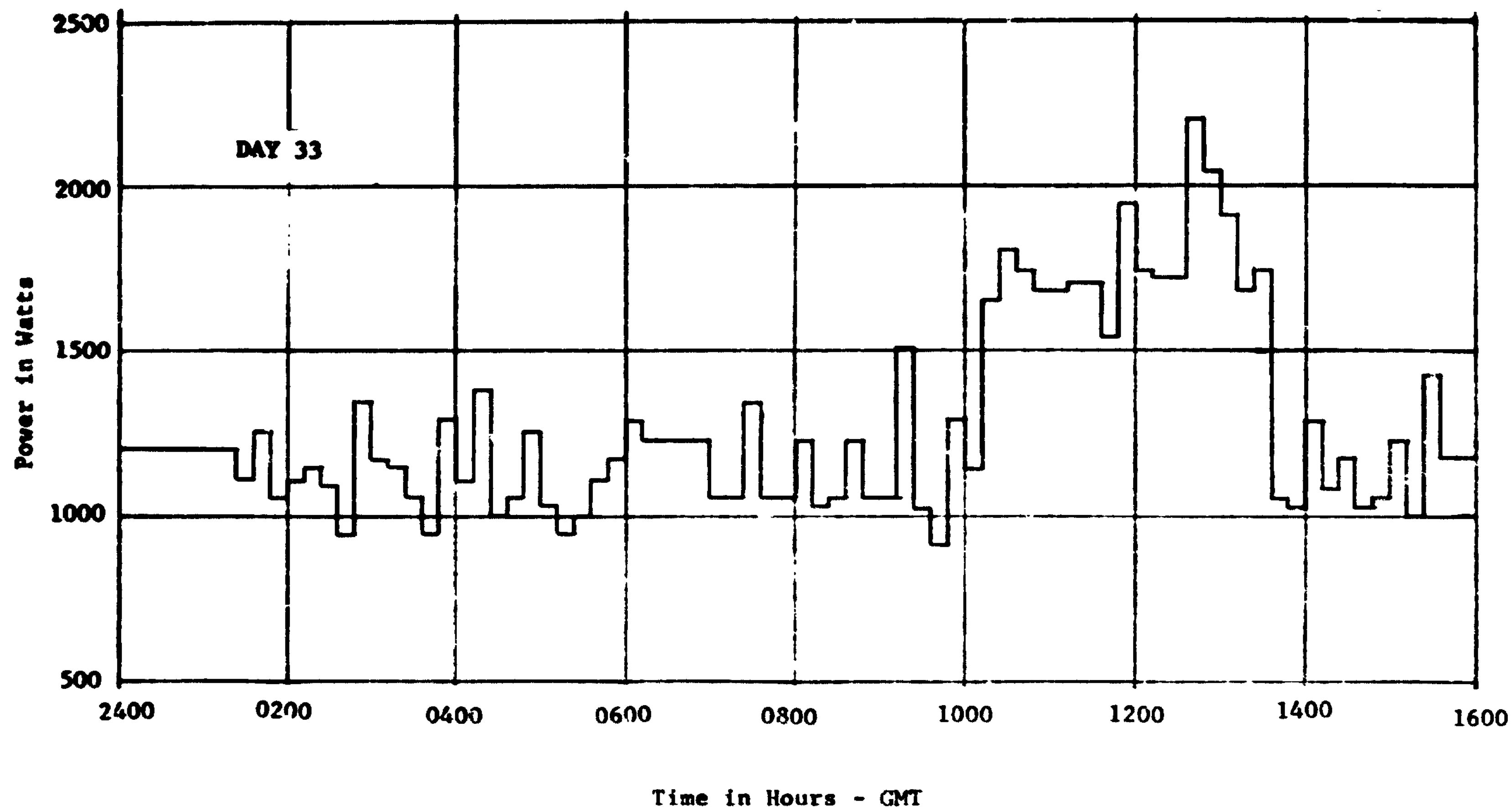

Figure 6.9 Peak CSM Power Transfer SL-1/2 For DAY 33

One day prior to launch of the SL-3 manned spacecraft, the thermostat setting for the MDA Wall Heaters was increased to the 70 degree point, which resulted in an increased load of 500 watts. At this point the average orbital load was 3600 watts. Additional loads included the docking lights, transponder, and tracking lights to support the rendezvous and docking maneuvers. However, the average loads of this period did not increase beyond 3900 watts and since the EPS capability was 5500 watts, a positive power margin of over 1600 watts was maintained.

As the astronauts began the activation process the loads were increased incrementally until at completion of activation, the total Skylab load requirement was 4800 watts average. The CSM load requirements were being supplied by the CSM fuel cells at this time, and therefore, power was not being transferred between the cluster and the CSM. The 5500 watt EPS capability during the activation period reflects an AM Reg Bus OCV setting of 29.4 volts. This high OCV setting resulted in a minimal power transfer between the AM and ATM EPSs. Initially, the AM transferred a small amount of power to the ATM systems but as the loads increased in the AM during the activation period, this was reversed and the ATM began to supply power to the AM loads.

On DAY 85 the Reg Bus OCV was adjusted to 29.2 volts to optimize the power system capability while equalizing the recharge time required for both the CBRMs and the PCGs. Figure 6.1 shows the history of each SL-3 OCV adjustment. Due to the large positive power margin during the first 20 days prior to CSM Fuel Cell shutdown it was not necessary to readjust the OCV for the Z-LV mode required for EREP. Nine EREP Passes were completed during this period. Table 6.VII is a summary of the geometry, beta angle and performance of the system during the first 9 EREP passes on the SL-3 mission. Figures 6.10 and 6.11 show the PCG, CBRM and Transfer Bus loads for typical days during the SL-3 mission, with an EREP pass both prior to and after fuel cell shutdown. Table 6.VIII gives the minimum and maximum bus voltages for these same two days.

On DAY 95, when the CSM Fuel Cells were deactivated, it was necessary to reduce the AM Reg Bus OCV adjustment to ensure that the AM DOD constraint would not be violated. This adjustment made available more of the ATM capability and, therefore, resulted in an increase in the EPS total capability. The total cluster load requirement at the time was 5850 watts average. When the requirement was compared to the power capability of 7000 watts at the 28.9 volt OCV setting, a positive power margin of approximately 1200 was noted.

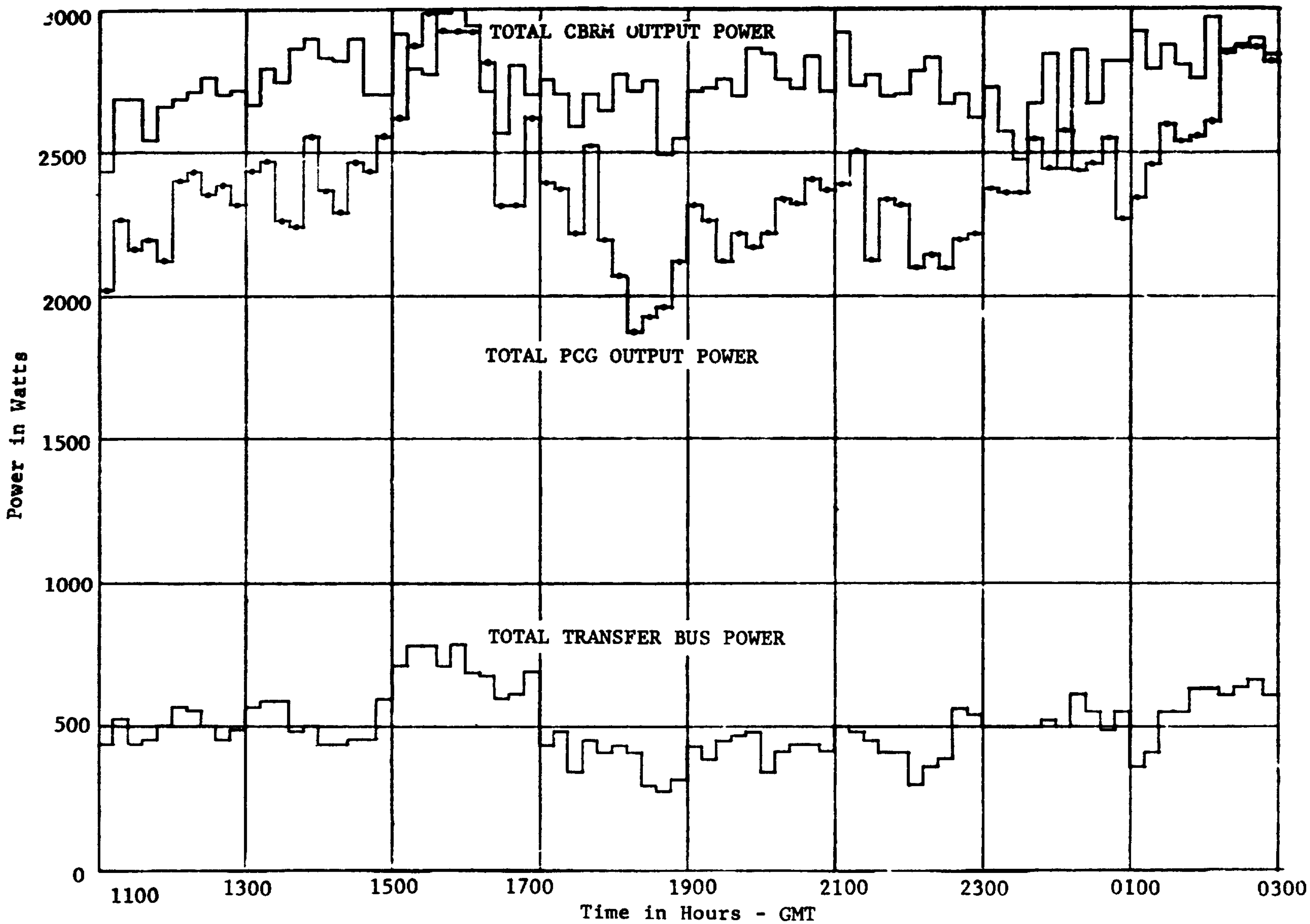

Figure 6.10 CBRM, PCG and Transfer Bus Power For DAY 90

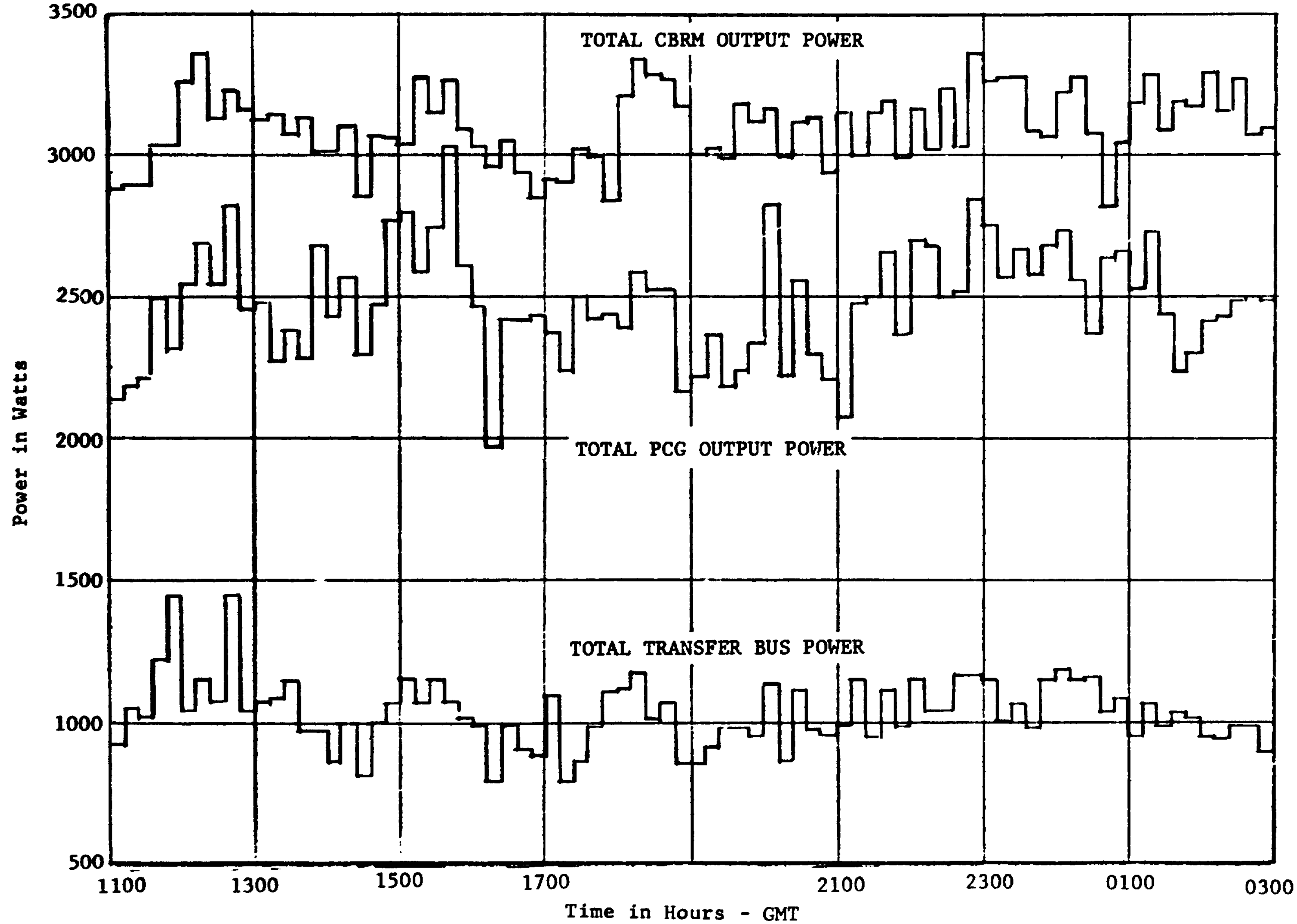

Figure 6.11 CBRM, PCG and Transfer Power SL-3 For DAY 113

EREP PASS	DAY	Z-LV DURA (MIN)	BETA ANGLE	MAX DOD (%) ATM PRED	MAX DOD (%) ATM ACT	MAX DOD (%) AM PRED	MAX DOD (%) AM ACT	OCV VOLTS BUS 1 PRED	OCV VOLTS BUS 1 ACT	OCV VOLTS BUS 2 PRED	OCV VOLTS BUS 2 ACT	Z-LV LOADS (WATTS) PRED	Z-LV LOADS (WATTS) ACT
1	82	35	-4.6	**	*	**	*	**	29.45	**	29.48	4643	*
2	83	39	-0.8	**	14.6	**	15.4	**	29.45	**	29.48	5230	5247
3	84	16	3.0	**	16.3	**	28.4	29.4	29.45	29.4	29.48	5660	5209
4	84	32	3.3	20	*	34	*	29.4	29.45	29.4	29.48	5309	5191
5	87	37	16.1	**	*	**	28.0	29.0	29.12	29.0	29.18	5416	5149
6	88	36	20.1	**	39.0	**	33.67	**	29.12	**	29.18	5118	4946
7	90	25	29.3	**	23.5	**	31.6	**	29.12	**	29.18	5276	5535
8	90	29	31.3	**	*	**	*	**	29.12	**	29.18	4974	*
9	91	29	33.6	**	31	**	*	**	29.12	**	29.18	5550	5845

* DATA NOT AVAILABLE

** DOD PREDICTIONS WERE NOT COMPUTED FOR EREP PASSES PRIOR TO CSM FUEL CELL SHUTDOWN

Table 6.VII. EREP Summary for SL-3

EREP PASS NO	DAY	Z-LV DUR A (MIN)	BETA ANGLE (DEG)	MAXIMUM DOD (%)				OCV (VOLTS)				Z-LV LOADS (WATTS)	
				ATM		AM		BUS 1		BUS 2			
				PRED	ACTUAL	PRED	ACTUAL	PRED	ACTUAL	PRED	ACTUAL	PRED	ACT.
10	111	39	27	29	37	37	34	28.9	28.9	29.1	29.1	5622	5504
11	112	35	22	38	39	34	36	28.9	29.9	29.1	29.1	5597	5729
12	112	7	21.4	31	23.5	30.5	16	28.9	28.9	29.1	29.1	5554	--
13	113	35	17.1	41	40	36	36	28.9	28.9	29.1	29.1	5504	5775
14	114	31	12.4	38	38	27	29.5	28.9	29.0	28.9	29.0	5640	5880
15	114	10	11.7	22	23	14	16	28.9	29.0	28.9	29.0	5355	5765
16	116	16	1.4	29	24	18	18	29.0	29.0	29.0	29.0	6394	6055
17	117	16	-3.2	24	24	19.7	19	29.0	29.0	29.0	29.0	5866	6260
18	119	32	-12.3	31	27.5	34	34	29.2	29.27	29.2	29.25	6020	6200
19*	120	23	-16.7	27	27	23	27	29.1	29.1	29.0	29.0	6069	6096
20*	120	19	-17.0	26	26	24	26	29.1	29.1	29.0	29.0	6146	6037
21	121	15	-20.2	22	23.5	18	24	29.1	29.1	29.0	29.0	6085	6140
22	CANCELLED												
23	121	11	-21.7	22	22	18	20	29.1	29.1	29.0	29.0	6259	5807
24	122	12	-24.5	22	23	18	22	29.1	29.1	29.0	29.0	6107	6346
25	122	25	-25.3	27	27	24	28	29.1	29.1	29.0	29.0	6207	6247
26	122	16	-25.8	25	23	18.5	18	29.1	29.1	29.0	29.0	6205	6338
27*	124	22	-29.6	25	24	19	22	29.1	29.1	29.0	29.0	6037	6141
28*	124	28	-29.9	33	31	33	28	29.1	29.1	29.0	29.0	5972	5825
29	124	27	-33.4	31	26	27	20	29.1	29.1	29.0	29.0	6138	5986
30	CANCELLED												
31*	125	31	-37	30	32	26	31	29.1	29.16	29.0	29.1	6026	6138

*BACK-TO-BACK EREP

Table 6.VII. EREP Summary for SL-3 (cont.)

EREP PASS NO	DAY	Z-LV DUR A (MIN)	BETA ANGLE (DEG)	MAXIMUM DOD (%)				OCV(VOLTS)				Z-LV LOADS (WATTS)	
				ATM		AM		BUS 1		BUS 2			
				PRED	ACTUAL	PRED	ACTUAL	PRED	ACTUAL	PRED	ACTUAL	PRED	ACT.
32*	125	22	-37	36	34.5	32	38	29.1	29.16	29.0	29.1	6208	6018
33*	126	31	-40.3	24	26	28	32	29.17	29.16	29.10	29.23	6100	6126
34*	126	18	-40.5	26.5	22	34	30	29.17	29.16	29.1	29.23	6014	5772
35	127	33	-43.2	28	37	30	36	29.17	29.16	29.23	29.23	6265	6003
36	127	9	-44.2	19	22	17.5	19	29.17	29.16	29.23	29.23	5756	5991
37	128	9	-45.7	17.5	19	16.5	17	29.17	29.17	29.23	29.23	5979	5846
38	129	14	-47.5	19.5	22	20	24	29.17	29.17	29.23	29.23	5877	5906
39	129	22	-47.9	23	25	27	23	29.17	29.17	29.23	29.23	5675	5852
40	130	14	-49	17.5	15.5	16	19	29.17	29.17	29.23	29.23	5916	6012
41	131	38	-49.4	32	39	36	43	29.35	29.29	29.35	29.34	6208	6219

*BACK-TO-BACK EREP

Table 6.VII. EREP Summary for SL-3 (cont.)

BUS	MINIMUM VOLTAGE (VOLTS)		MAXIMUM VOLTAGE (VOLTS)	
	DAY 90	DAY 113	DAY 90	DAY 113
ATM MAIN 1 and MAIN 2	28.69	28.66	28.90	28.81
REG 1 and 2	28.74	28.50	28.98	28.82
TRANSFER 1 and 2	28.82	28.58	28.98	28.82
AM 1 and 2	28.74	28.50	28.90	28.75
EPS 1 and 2	28.20	27.96	28.28	28.27
OWS 1 and 2	28.22	27.97	28.64	28.36

Table 6.VIII. Bus Voltages DAYs 90 and 113

After the CSM Fuel Cells were deactivated on SL-3, the Skylab EPS provided an average of 1050 watts to the CSM main buses. During the checkout and reentry simulations on DAY 130, the CSM required a peak power of 2229 watts from the Skylab power system.

To ensure adequate capability for contingency cases during the installation of the "Rate Gyro Six Pack" on DAY 105, the OCV was adjusted to 29.1 volts. Although this resulted in a reduced capability for the EPS of 400 watts, it provided protection for the ATM battery system in event of a contingency situation by shifting the load toward the AM power system. This was necessary since the ATM battery system had shown degradation in excess of the premission predictions. The "Rate Gyro Six Pack" installation was routine and the OCV was returned to the 28.9 volt setting.

On DAY 112, the OCV was adjusted to 29.0 volts to increase the power system capability during the Z-LV attitude for EREP. Since the 29.0 volt OCV also provided a positive power margin for solar inertial operation, the setting was not adjusted after the EREP pass was complete. Similar OCV adjustments of 29.1 and 29.2 volts were made on DAY 125 and 126 respectively to further increase the Z-LV power capability.

A failure of the charger on CBRM 5 on DAY 123 resulted in a reduced ATM power system capability. The reduction in capability at the 29.0 volt OCV setting was only 100 watts and, therefore, the impact on the solar inertial capability was negligible.

Since the power system integrity during the Z-LV attitude depended on restricting the DOD of the batteries, it was necessary to evaluate each planned Z-LV and predict the maximum DOD. After the inflight battery capacity tests were performed, it was determined that beginning with EREP 10, the ATM permissable DOD was 45 percent of rated capacity and the AM was 50 percent. Using these criteria, power management techniques were implemented if the DOD predictions indicated a violation of the criteria for either or both systems.

It was possible to support all of the EREP passes shown on Table 6.VII by using power management techniques. The resulting battery DODs are also shown in the table.

With the exception of the CBRM 5 charger failure, the SL-2 failure of CBRM 3 regulator and the off-nominal performance of CBRM 17, all EPS subsystems continued to operate normally during the SL-3 mission.

To establish a configuration of the AM/OWS EPS which was acceptable for the contingency requirements of a failure of both AM coolant loops, the power transfer relays "AM TRANSFER", were commanded open prior to SL-3 separation. At this point, each EPS began to operate independently, supplying those loads connected to their load buses.

The AM and ATM electrical power systems continued to operate separately during the entire storage period between the SL-3 and SL-4 missions. The average power system capability for this period varied as the beta angle varied; Figure 6.1 shows the capability and average load for the AM and ATM Electrical Power Systems respectively.

The AM electrical power system operated normally during the entire storage period without failures or off-nominal performance. The average AM electrical load during this period was 1100 watts and the capability of the system varied from a minimum of 2900 watts to a maximum 3600 watts at launch of SL-4. The resulting PCG battery DOD for the 1100 watt load over the range of beta angles encountered during the storage period varied from six to eight percent.

During the storage period the ATM electrical power system operated normally with the exception of CBRM 17. Due to the off-nominal operation of this component its contribution to the total ATM output was 80 percent less than that of the remaining 15 CBRMs. On DAY 151 CBRM 17 was removed from the load bus for a period of 20 hours; after it was returned to the load bus it began to function properly, and for the remainder of this period its contribution to the total ATM power capability was equal to that of the other 15 active CBRMs.

The average ATM load requirement during the storage period was 2000 watts and the average system capability varied from a minimum 3800 watts to a maximum of 4900 watts at the launch of SL-4. The resulting CBRM battery DOD for the 2000 watt load over the range of beta angles encountered during the storage period varied from 12 to 14 percent.

One day prior to the launch of the SL-4 manned spacecraft, the thermostat setting for the MDA Wall Heaters was once more increased to the 70°F setting, which resulted in an increased load on the AM system of 500 watts to a total load average of 1600 watts. Additional loads were added, such as the tracking lights, transponder and docking lights, to support the rendezvous and docking operations. The average load on the AM system for this period was a maximum of 1900 watts, and the ATM average load remained at 2000 watts. Since the power system capability for both systems was the highest value of the entire storage period at this point, a large positive power margin was still maintained for each system.

When the MDA hatch was removed and the cluster activation began, one of the first tasks accomplished was to parallel the AM and ATM electrical power systems and adjust the AM OCV. The OCV was adjusted to 29.1 volts for the first activation day and then was increased to 29.3 volts for the remainder of the activation period. The power system capability of the two systems operating in parallel at the 29.1 volt OCV was 8000 watts. The adjustment to 29.3 volts caused a decrease in the cluster capability to 7900 watts.

As the cluster was activated the load increased incrementally until, at the end of the activation period, the load was 4800 watts average when the crew was awake and 4200 watts during the crew sleep period. Compared to the 7900 watt capability for this period a minimum power margin of 3100 watts existed.

The CSM load requirements were supplied by the CSM fuel cells for the first 20 days of the SL-4 mission and therefore, the power transfer to the CSM was zero during the activation period. At the 29.1 and 29.3 volt OCV the power transfer from the ATM to the AM was minimal. As the loads on the AM system increased during the crew awake period the amount of power being transferred increased; the average power transfer, when the cluster average load was 4800 watts, was 350 watts. When the cluster average load dropped to 4200 watts, during the crew sleep period, the average power transfer was 100 watts. Figure 6.12 shows the PCG and CBRM power requirements for a typical day together with the transfer bus power requirements.

The AM and ATM power systems continued to operated in parallel for the remainder of the SL-4 mission to supply the total cluster power requirement. Since both systems had a constraint on the maximum DOD it was necessary to periodically adjust the AM OCV to ensure that the constraints were not violated. As the OCV was adjusted the total cluster power system capability changed to reflect the usable capability at that specific setting. Figure 6.1 shows the SL-4 capability history for the various OCV settings during the mission.

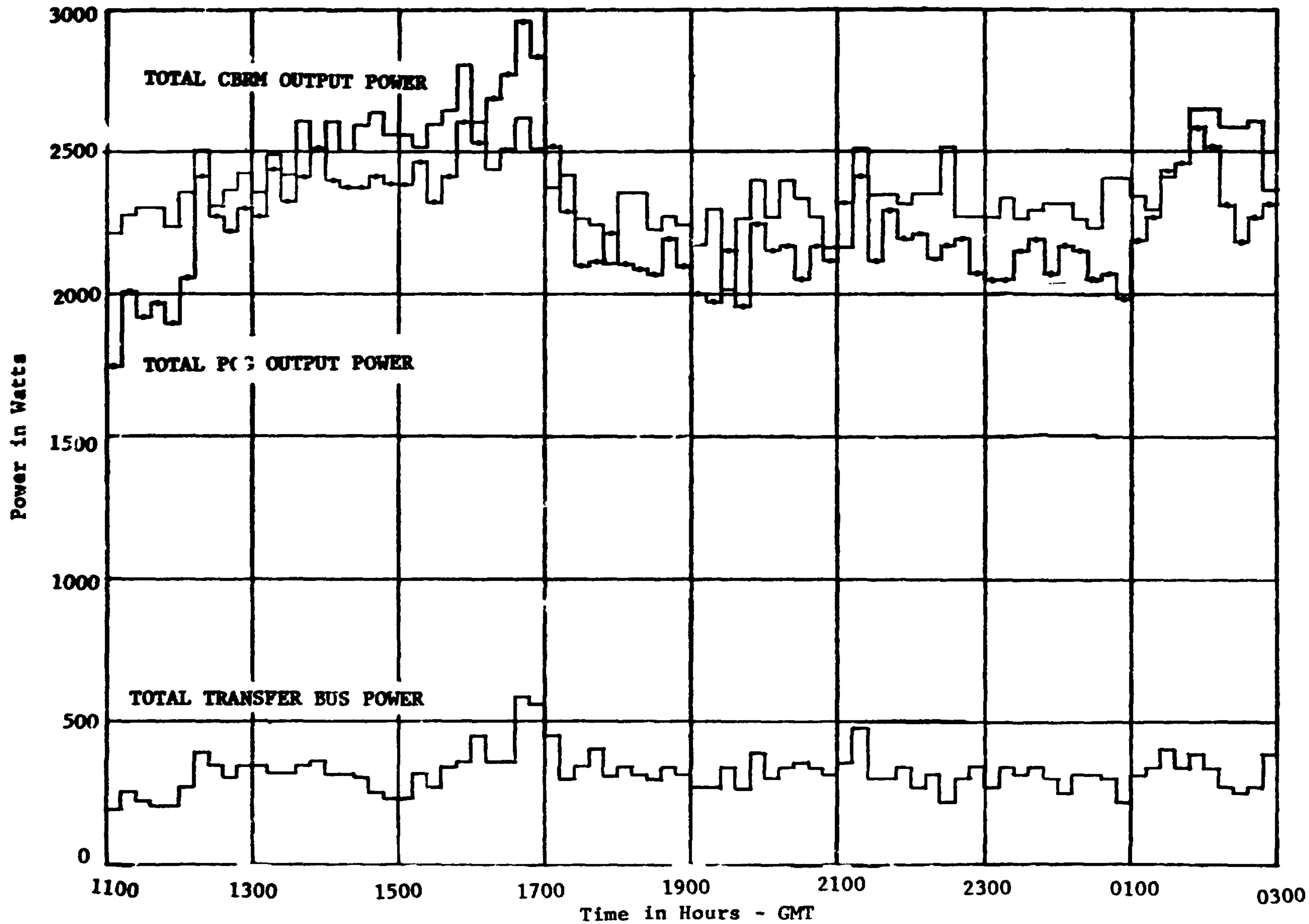

Figure 6.12 CBRM, PCG and Transfer Bus Power For DAY 201

On DAY 206 the CSM fuel cells were deactivated and the cluster power system supplied the total CSM power requirement for the remainder of the mission. The AM Reg Bus OCV was adjusted to 29.1 volts to insure that the AM DOD constraint was not violated because of the increase in load. The total cluster load, including the CSM, increased to 5800 watts average when the crew was awake and 5200 watts average during crew sleep periods. Compared to the 6200 watt power system capability at the 29.1 volt OCV setting on DAY 206, a minimum power margin of 400 watts was available.

Figure 6.13 shows the PCG and CBRM requirements and the transfer bus power for a typical SL-4 mission day after fuel cell deactivation. Table 6.IX gives the minimum and maximum bus voltages for these mission days plotted in Figures 6.12 and 6.13.

BUS	MINIMUM VOLTAGE (VOLTS)		MAXIMUM VOLTAGE (VOLTS)	
	DAY 201	DAY 246	DAY 201	DAY 246
ATM MAIN 1 and MAIN 2	28.75	28.75	28.93	28.95
REG 1 and 2	28.81	28.90	29.14	29.22
TRANSFER 1 and 2	28.90	28.90	29.14	29.22
AM 1 and 2	28.74	28.83	29.06	29.14
EPS 1 and 2	28.28	28.43	28.51	28.67
OWS 1 and 2	28.22	28.36	28.77	28.77

Table 6.IX. Bus Voltages DAY 201 and DAY 246

After the CSM fuel cells were deactivated on DAY 206, the cluster power system provided an average of 1050 watts to the CSM main buses. During the checkout and reentry simulations on DAY 265 the CSM obtained its peak power from the power system. The CSM power requirement was supplied and the minimum interface voltage requirement was met by the cluster power system for the entire Skylab mission without the need for CSM load management.

The DOD constraints during the Z-LV orientation required for the EREP passes on both the AM and ATM power systems were different from the solar inertial constraint, to permit deep DODs for this limited number of cycles. Up to DAY 43 the constraint on the ATM batteries permitted a maximum of 9.0 ampere hours (45 percent DOD) to be removed from any CBRM; similarly the AM constraint was 16.0 ampere hours maximum (48.5 percent DOD).

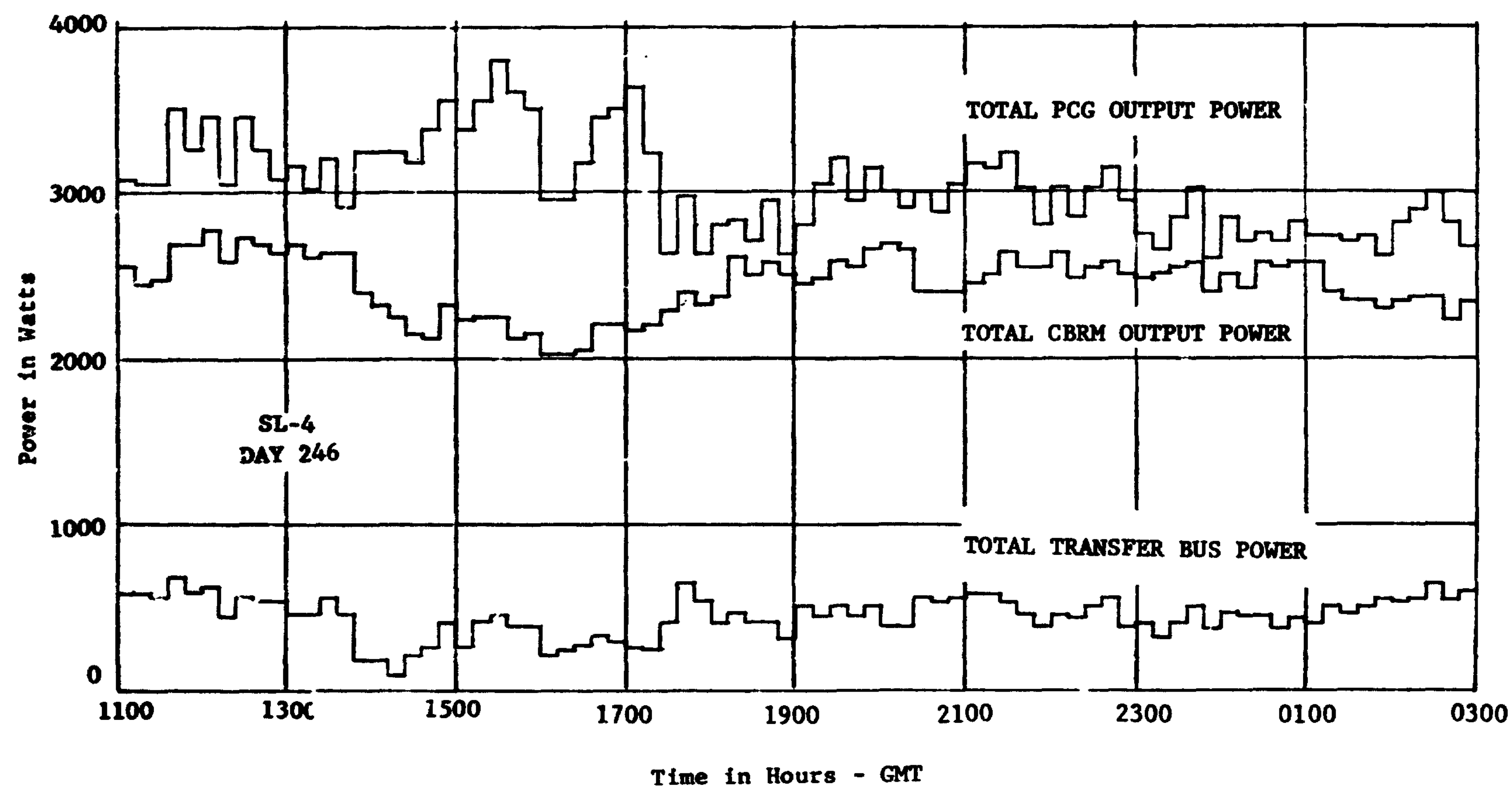

Figure 6.13 CBRM, PCG and Transfer Bus Power for DAY 246

On DAY 229 a battery capacity test was conducted on CBRM 10 and CBRM 18. Since the measured capacity during this test was less than the predicted value, the ATM maximum DOD constraint was decreased to 8.0 ampere hours (40 percent DOD). Since this decrease in stored energy available from the ATM system restricted to a degree the types of EREP passes permissible, on DAY 243 the AM criteria was relaxed to permit a maximum of 20.0 ampere hours (60.6 percent DOD) to be removed from the PCG batteries.

It was possible to support all of the EREP passes shown on Table 6.X by using power management techniques. Most of the numerous OCV adjustments shown on Figure 6.1 for the SL-4 time period were power management techniques necessary to optimize the capability for EREP passes. All of the OCV settings used during the SL-4 mission provided adequate capability to maintain a positive power margin for the solar inertial orientation.

EREP pass 29, a back-to-back two data take pass, resulted in a violation of the 8.0 ampere hour DOD constraint on CBRM 11. The actual DOD was 8.23 ampere hours; the DOD on the remainder of the CBRMs for this pass was less than 8.0 ampere hours. Since the excursion above 8.0 ampere hours was small and at a relatively low discharge rate, CBRM 11 did not disconnect from the system. Following the return to solar inertial, enough energy was available for charging to completely recharge the battery the following orbit. Therefore, the violation of the constraint did not adversely affect the ATM power system performance and was not considered off-nominal operation.

On DAY 259 during EREP pass 45 the actual ATM DOD of 8.26 A-H again exceeded the 8.0 A-H maximum criteria. However, since the excursion was small the power system continued to function normally, and all system parameters were acceptable.

During the SL-4 manned mission one of the major experiment objectives was to obtain data on the Comet Kohoutek. In order to obtain the proper angle for comet observation it was necessary to maneuver the vehicle away from the solar inertial attitude. Since the total cluster power system output capability was reduced as the vehicle was maneuvered out of solar inertial the battery DOD for both the PCGs and the CBRMs was computed for each pass to insure that the power system integrity was protected. Table 6.XI lists the Kohoutek passes and the resultant battery DODs. The JOP 18D Kohoutek passes were the most severe on the power system because the change in the vehicle position was greater for this type of comet observation. The relatively low DOD for many of the passes reflect the vehicle maneuvers centered around orbital midnight and therefore the resulting DOD approximated that of a normal solar inertial night period.

EREP PASS NO	DAY	Z-LV DUR. (MIN)	BETA ANGLE (DEG)	MAXIMUM DOD (%) ATM PRED.	ATM ACT.	AM PRED.	AM ACT.	OCV (VOLTS) BUS 1 PRED.	BUS 1 ACT	BUS 2 PRED.	BUS 2 ACT.	Z-LV LOAD PRED.	Z-LV LOAD ACT.
1	CANCELLED												
2	CANCELLED												
3	CANCELLED												
4	201	25	-31.6	19.0	22.1	19.0	17.7	29.30	29.30	29.26	29.26	5176	4821
5	202	25	-27.0	20.0	19.8	29.0	14.9	29.30	29.30	29.26	29.26	5269	4873
6*	203	13	-22.4	-	-(1)	-	-(1)	29.30	29.30	29.26	29.26	5016	5444
7*	203	15	-22.1	18.0	-(1)	30.0	-(1)	29.30	29.30	29.26	29.26	4768	5115
8*	204	14	-18.0	20.0	21.1	19.0	22.4	29.30	29.30	29.26	29.26	5375	5060
9*	204	11	-17.7	19.4		22.8	25.2	29.30	29.30	29.26	29.26	5097	4698
10	205	89	-13.3	31.0	33.7	32.0	30.4	29.30	29.30	29.26	29.26	5259	5011
11	206	103	- 9.1	38.5	41.0	43.1	42.3	29.11	29.13	29.09	29.11	6130	5925
12	208	41	- 0.9	40.0	40.5	47.5	37.2	29.10	29.14	29.10	29.13	6133	5812
CAL	210	32	+ 4.4	31.0	24.6	26.0	21.7	29.0	29.14	29.0	29.13	5912	
14	210	94	+ 4.9	40.0	38.8	48.0	34.4	29.10	29.14	29.10	29.13	6134	
15	215	21	+22.5	39.1	40.5	44.8	37.9	29.05	29.09	29.15	29.13	5649	5533
16	219	24	+26.4	39.0	40.3	43.0	37.5	29.09	29.09	29.13	29.20	5870	5392(2)
17	219	24	+26.6	41.0	38.8	43.0	46.2	29.09	29.09	29.13	29.33	5537	5296
18	233	111	- 9.5	33.0	35.7	44.0	43.5	29.4	29.4	29.4	29.[illegible]	5504	5350
19	235	88	-18.1	38.0	34.9	33.0	27.6	29.10	29.15	29.10	29.19	5572	5507
20	236	88	-24.0	34.6	39.4	39.5	37.6	29.30	29.25	29.30	29.23	5646	5966
21	238	88	-33.3	36.0	35.9	29.0	32.0	29.20	29.17	29.20	29.20	5585	5734
CAL	239	30	-36.9	24.7	24.[illegible]	16.7(3)	20.9	29.0	29.0	29.0	29.0	5714(3)	6317
22	239	88	-37.8	36.5(4)	28.7	33.3(4)	24.0	29.2	29.24	29.2	29.16	5626	5711
23	240	94	-42.4	34.5	34.9	40.0	32.4	29.3	29.27	29.30	29.30	5617	5529
24	241	93	-46.8	35.0	37.3	38.4	28.3	29.30	29.18	29.30	29.19	5554	5257
25	242	26	-53.3	31.8	36.3	39.0	47.3	29.50	29.48	29.50	29.48	5000	5266
26	243	28	-56.1	34.4	38.4	43.1	42.7	29.40	29.40	29.40	29.30	5605	5688
27	244	96	-60.1	35.8	36.8	39.9	36.3	29.40	29.40	29.40	29.42	5543	5413
28	CANCELLED												
29,29*	246	100	-67.0	36.5	41.2	47.2	52.6	29.50	29.61	29.50	29.59	5797	5680
30	250	16	-68.6	8.0(5)	6.1	7.8(5)	6.6	29.4	29.4	29.4	29.4	5700	5697
31	251	11	-65.7	8.0(6)	8.9	7.8	9.3	29.4	29.4	29.4	29.4	5796	5963
32	252	17	-62.6	20.1	11.1	23.6	12.6	29.4	29.4	29.4	29.4	5644	5628
33	CANCELLED												
34	CANCELLED												
35	253	29	-58.4	14.0	14.4	29.0	24.4	29.5	29.4	29.5	29.4	5680	5704

* Back to Back EREP

Table 6.X. EREP Summary for SL-4

EREP PASS NO.	DAY	Z-LV DUR. (MIN)	BETA ANGLE (DEG)	MAXIMUM DOD (%)				OCV (VOLTS)				Z-LV LOAD	
				ATM		AM		BUS 1		BUS 2			
				PRED	ACT	PRED	ACT	PRED	ACT	PRED	ACT	PRED	ACT
36	CANCELLED												
37	254	96	-54.2	33.0	39.2	51.0	40.0	29.5	29.4	29.5	29.4	5630	5640
38	CANCELLED												
39	CANCELLED												
40	256	97	-45.9	32.0(6)	37.9	43.0(5)	57.0	29.5	29.4	29.5	29.4	5666 (6)	5994
41	257	98	-41.0	39.0	37.8	50.0	45.4	29.3	29.3	29.3	29.25	6277	6042
42	258	103	-35.4	36.4	33.2	53.7	49.2	29.5	29.47	29.5	29.5	5627	5865
43	CANCELLED												
44	259	92	-32.3	34.1	36.5	53.4(7)	38.3	29.4	29.3	29.4	29.3	5981 (7)	5674
45	259	106	-31.0	29.6	41.3	52.0	44.6	29.5	29.3	29.5	29.3	5688	5704
46	260	31	-26.0	25.6	25.3	27.6	22.5	29.3	29.14	29.3	29.14	5676	5810
47	261	102	-21.3	32.0	35.0	47.0	46.3	29.5	29.40	29.5	29.39	5691	5749
48	262	40	-16.6	32.5	32.9	50.5	44.6	29.4	29.4	29.4	29.4	5777	5753
49	263	100	-12.3	31.0	32.5	56.0	47.9	29.5	29.44	29.5	29.44	5696	5704
50	264	93	- 7.4	31.0	34.1	46.0	47.5	29.30	29.27	29.50	29.33	5689	5401

NOTES:

(1) NO DATA AVAILABLE

(2) THE MOLE SIEVE B FAN AND AREA FANS WERE OFF LOADED RESULTING IN A 232 W REDUCTION NOT CONSIDERED IN THE LOAD PREDICTION.

(3) PREDICTION MADE WITH MDA WALL HEATERS OFF LOADED. DURING MANEUVER WALL HEATERS WERE NOT OFF LOADED.

(4) VEHICLE RETURNED TO SI 61 MINUTES SOONER THAN SCHEDULED.

(5) PREDICTION BASED ON PIE CHART WHICH HAD 2 MINUTES MORE MANEUVER AND 2 MINUTES LESS DATA TAKE, AND WITH THE MDA WALL HEATERS OFF LOADED.

(6) PREDICTION BASED ON 29.5 VOLT OCV AND OFF LOAD OF AM AND MDA WALL HEATERS. MANEUVER WAS PERFORMED AT 29.4 OCV AND NO OFF LOADING.

(7) PREDICTION MADE WITH NO OFF LOADING. DURING MANEUVER MDA WALL HEATERS WERE OFF LOADED.

Table 6.X. EREP Summary for SL-4

CBRM 5 experienced a charger failure during the SL-2 mission and could only be used by managing real-time. An operational characteristic of CBRM 5 was that once each orbit it would automatically disconnect from the bus due to battery over-voltage at the point of 100 percent charge. Once disconnected it could then be reconnected to the bus and would operate normally until the next orbit when it would once more disconnect. Due to the limited amount of crew time available for EPS management and the limited number of ground stations available per orbit, CBRM 5 was not used for normal EPS operations. Near the end of the SL-4 mission two JOP-13 passes and the EREP 50 pass required additional capability to insure that the 8.0 A-H maximum DOD criteria was not violated. CBRM 5 was managed by ground control to provide the additional capability for the passes.

Many of the changes in battery DOD during the Skylab mission were related to the adjustment of the Reg Bus OCV, but in addition the DOD also tracked the beta angle. As the beta angle increased in magnitude (either positive or negative) from zero degrees, the DOD decreased. Above 69.5 degrees beta angle the vehicle was in continuous sunlight and the batteries did not discharge at all. At zero degrees beta angle, the orbital night period was maximum and thus the DOD increased. Figure 6.14 plots the average solar inertial DOD for both the CBRMs and the PCGs and shows the relationship to the beta angle for the mission.

To facilitate the post-mission PCG battery verification test with the desired discharge current, the "AM-TRAN" power transfer relays were opened during the SL-4 deactivation of the cluster. Prior to opening the relay contacts, an astronaut adjusted the OCV to Reg Bus 1 to 29.1 volts and Reg Bus 2 to 29.8 volts. Power transfer between the systems was terminated at this point and each power system supplied its own load requirement for the remainder of the SL-4 mission.

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EXP.	DAY	MAX CBRM DOD%	MAX PCG DOD%
S019	196	15.0	17.7
S201	197	17.0	16.0
S232	198	23.6	32.5
S063	206	23.9	17.8
S201	206	26.1	21.3
S183	207	24.8	16.9
S019	208	24.4	19.8
S063	209	24.6	17.8
S063	210	24.3	19.8
S063	211	26.7	15.8
S201K	212	27.8	17.7
S201G	212	25.0	17.6
S019	214	28.8	16.9
S183	214	28.5	16.7
S019	215	26.8	16.6
S201	217	24.8	17.8
S019	217	24.5	17.3
S019K	117	24.8	16.6
S063	218	25.5	17.8
S183	219	28.8	29.5
JOP18D	220	25.4	31.6
S019	220	33.5	18.9
S063	221	25.2	16.6
JOP18D	222	26.6	26.8
S063	223	32.1	20.5
S063	224	28.4	15.4
S201	224	38.8	23.3
JOP18D	224	25.6	16.2
S019	224	27.6	17.7
JOP18D	225	26.3	16.5
S201	226	*	19.7
S201	230	34.4	25.4
JOP18D	230	*	20.1
JOP18D	231	27.3	19.4
JOP18	231	*	19.0
JOP18D	232	26.8	19.7
JOP18	232	*	17.8
JOP18D	233	25.2	20.5
S201	234	36.0	32.0
S063	234	31.5	20.1
S183	235	29.7	23.7
JOP18D	235	24.7	25.2
S019	236	30.6	16.2
JOP18D	237	24.0	17.8
S063	237	28.8	21.4
S201	238	28.6	22.5
JOP18D	238	23.4	17.4
S019	239	24.5	20.2
S019	240	26.8	17.8
S063	240	22.5	18.9
S063	241	20.7	15.5
S183	241	22.4	17.0
S201	242	19.1	20.1
S183	243	16.4	17.9
S019	243	16.1	17.2
S063	244	13.7	13.9
S201	244	12.9	13.4
S063	245	11.5	11.4
S019	246	9.0	10.2
S201	246	8.2	7.2
S201	257	20.2	19.9
S201	258	22.5	17.0
S063	259	24.8	18.2
S019	262	26.2	17.9
S201	263	25.6	*
S201	264	31.1	17.9

Table 6.XI. Kohoutek Pass DODs

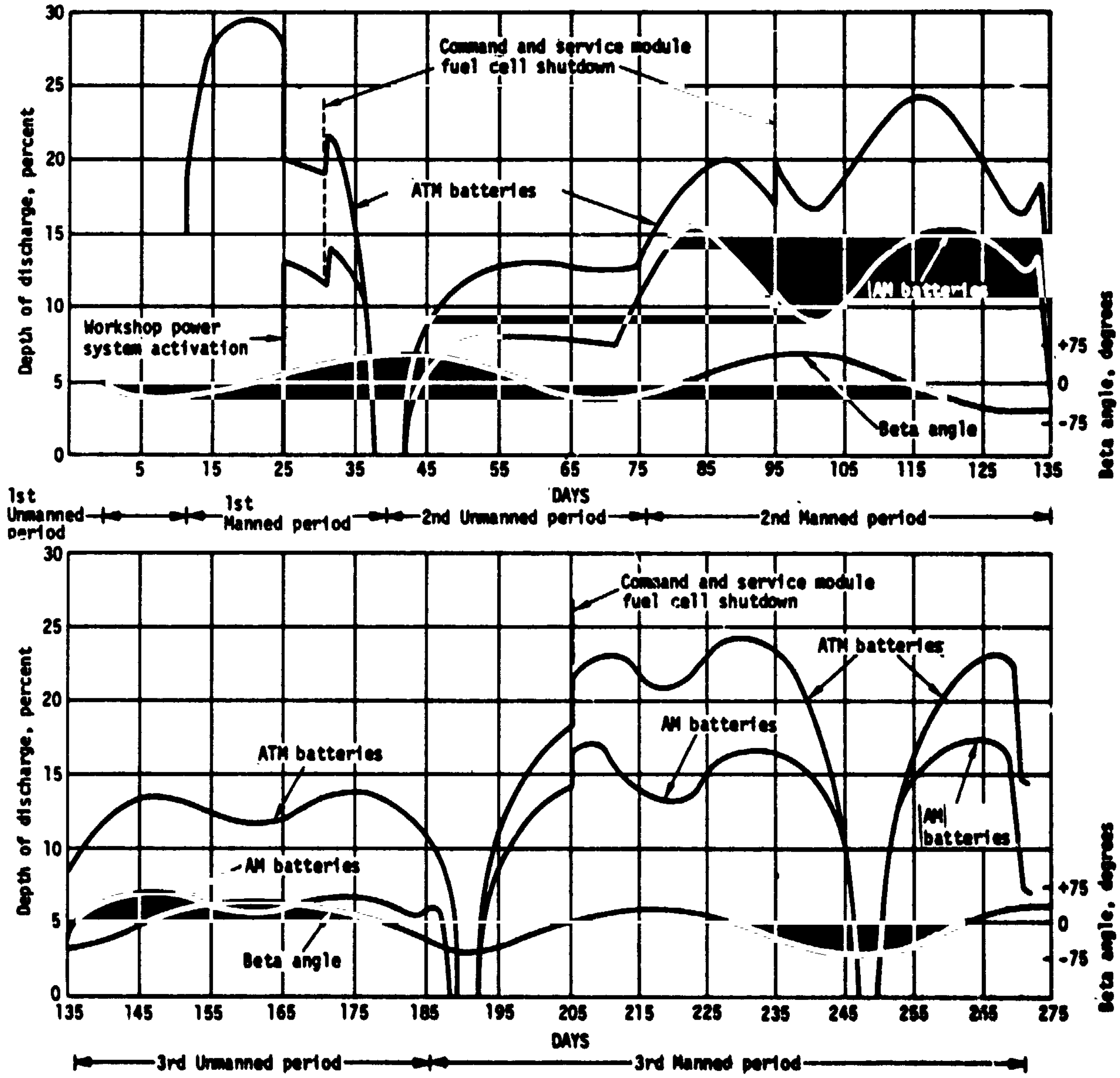


Figure 6.14 Mission ATM/AM DOD s

7. Module Hardware Mission Performance.

a. AM/OWS.

(1) Solar Arrays. The Solar Array Subsystem (SAS) design for the OWS consisted of two (2) wings, each consisting of a beam fairing and three (3) wing sections. Each wing section contained ten (10) identical active solar panels for a total of 30 panels per wing or 60 panels per system (Figure 7.1). Two (2) additional panels were included in each wing section to provide spacing between active panels and the beam fairing; one was a truss panel and the other a "dummy" (inactive) panel.

At approximately 63 seconds into the Skylab 1 flight, the vehicle experienced structural failure of the OWS Meteoroid Shield. This failure unlatched and partially deployed SAS Wing 2 Beam Fairing, as evidenced by the fairing secured bi-level event measurement and indications of solar cell illumination, verified by an increase in the Solar Array Group (SAG) voltages.

Following S-II cutoff at 589.2 seconds, all SAG voltages, with the exception of SAG 4 voltage, exhibited an increase as SAS Wing 2, no longer restrained by the launch vehicle acceleration forces, started to prematurely deploy. The S-II retro-rocket exhaust plume impinging on SAS Wing 2 contributed to the loss of the wing by causing it to shear off, thereby severing all electrical connections at approximately 593 seconds. At that time all SAG voltage measurements dropped to the level of PCG batteries and all SAS current measurements dropped to zero. Subsequently, no valid data was received from any SAS Wing 2 temperature or position measurements.

SAS Wing 1 attempted to deploy at the nominal time but was constrained in a partially deployed configuration by debris of the meteoroid shield. Wing section partial deployment in this configuration allowed sunlight to illuminate some solar cell modules and provided power approximately equivalent to one normally deployed module (1/240 of total SAS capability). Although insignificant in terms of supplying cluster loads, this output was utilized to allow some recharging of the AM batteries. The IU commands, the Exploding Bridgewire (EBW) electronic units, and the ordnance systems functioned as designed. The command sequences and results are shown in the Table 7.I. The SAS Wing 1 Beam Fairing ordnance was successfully detonated at the proper time by the pre-programmed primary command (Figure 7.2). The Beam Fairing left its secured position and deployed until it was constrained by debris from the meteoroid shield (as observed later by SL-2 crew). The backup system EBW was charged and fired by DCS ground command and operated nominally, but was ineffective in completing deployment. The SAS wing section EBW responded to the primary Charge and Reset

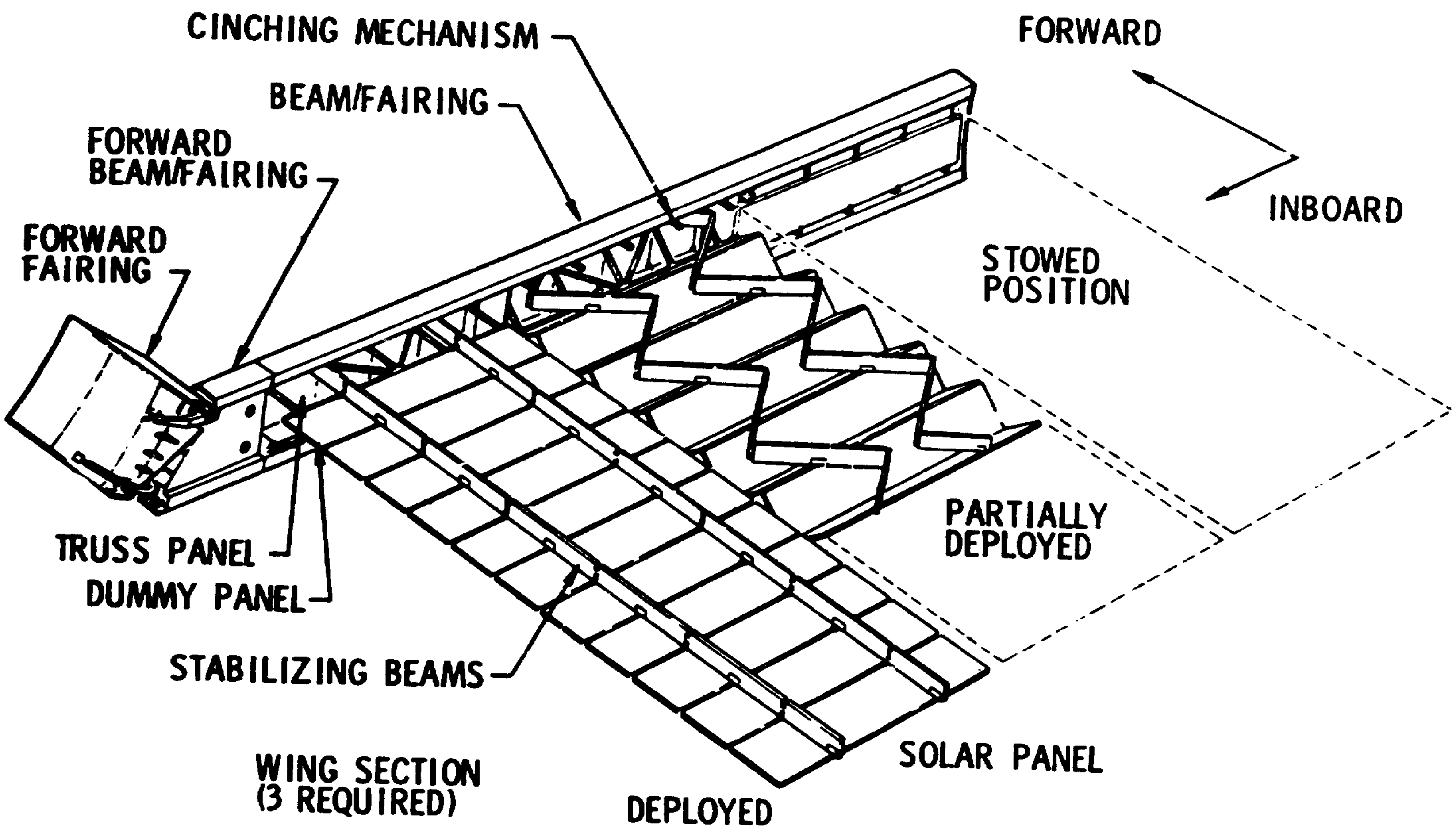


Figure 7.1 OWS Solar Array Wing Assembly

PRIMARY SYSTEMS

MEASUREMENT	TIME COMMAND ISSUED GMT	GET(SEC)	CMD SOURCE	REMARKS
SAS FAIRING				
EBW FU 2 CHG	18:10:00	2400	IU S/S 9	SAS WING 1 FAIRING
EBW FU 2 FIRE	18:10:05	2405	IU S/S 53	SECURED MEASUREMENT INDICATED
EBW FU 2 RST	18:10:10	2410	IU S/S 10	MOVEMENT AT 18:10:06
SAS WINGS				
EBW FU 2 CHG	18:22:00	3120	IU S/S 11	EBW DID NOT FIRE -
EBW FU 2 FIRE	18:22:05	3125	IU S/S 51	INTERLOCKED WITH FAIRING

SECONDARY SYSTEMS

MEASUREMENT	TIME COMMAND ISSUED GMT	GET(SEC)	CMD SOURCE	REMARKS
SAS FAIRING				
EBW FU 1 CHG	19:08:22	5902	DCS-182	PRIMARY SYS.
EBW FU 1 FIRE	19:08:42	5922	DCS-163	RELEASED
EBW FU 1 RST	19:09:10	5950	DCS-183	FAIRING
SAS WINGS				
EBW FU 1 CHG	19:20:56	6656	DCS-172	SAS WING 1 POSITION
EBW FU 1 FIRE	19:23:26	6806	DCS-162	MEASUREMENT INDICATED
EBW FU 1 RST	19:24:01	6841	DCS-173	MOVEMENT AT 19:23:28

Table 7.I EBW Command History for OWS Solar Array Deployment.

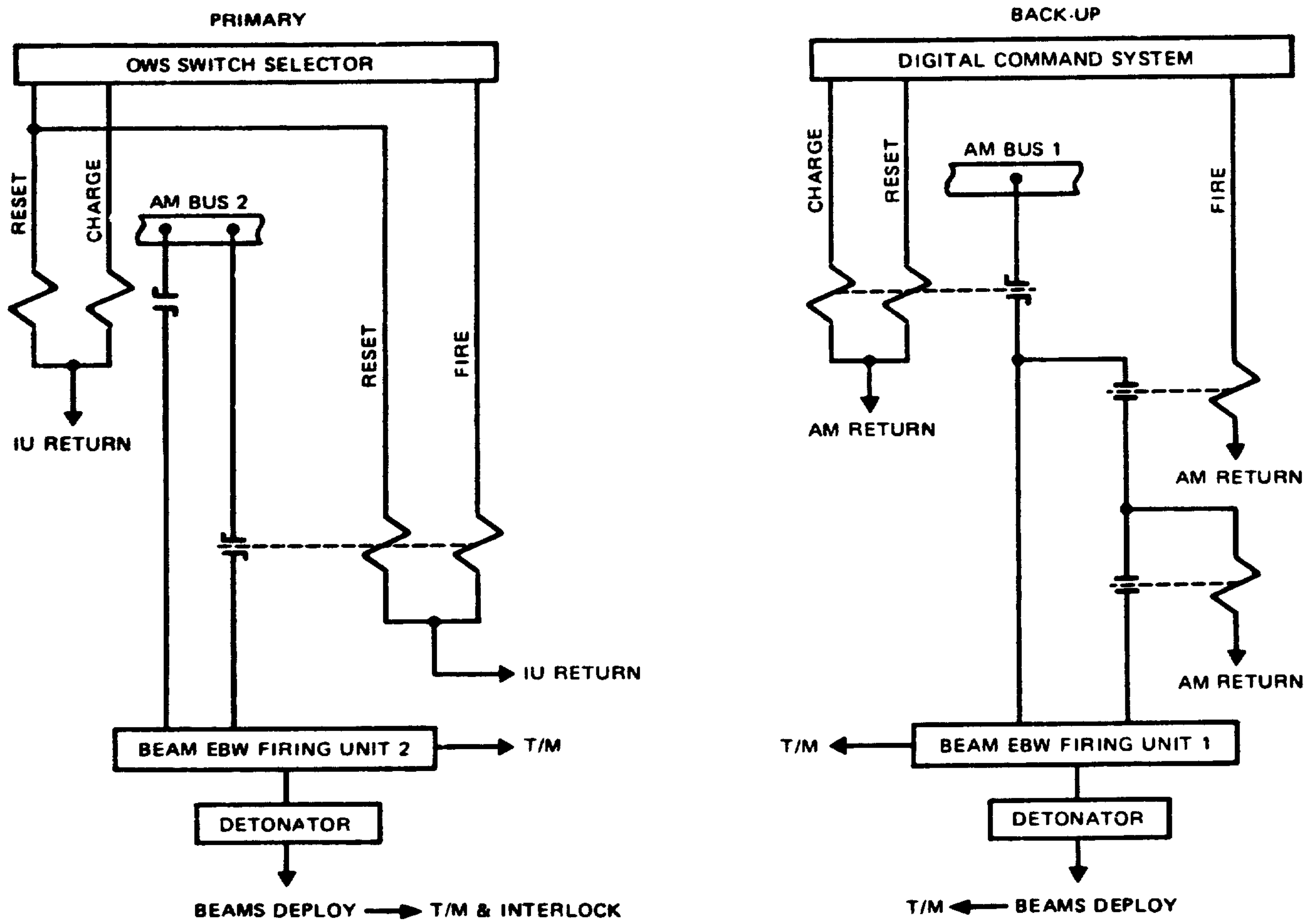


Figure 7.2 OWS Solar Array Beam Fairing Deployment Circuits (Primary and Back-up)

commands (Figure 7.3), but was prevented from firing the ordnance for deployment by an interlock which is only satisfied by full deployment of both Beam Fairings. The backup system was charged and fired by ground command and the Wing Sections were observed to partially deploy until contact with the OWS tank wall was made.

On DAY 25 the astronauts, during EVA, proceeded to deploy SAS Wing #1. A bolt cutter was used to sever the meteoroid shield restraining debris. A tether was tied to one SAS vent module and the astronaut stood erect under the tether applying a force to the beam fairing and breaking loose the actuator damper. The beam fairing deployed to the full open position in approximately 15 seconds. The wing sections partially deployed and then stopped because of the low temperature of the actuator dampers. A -45° pitch maneuver was made allowing direct solar energy to warm the beam fairings. In approximately 5 hours (DAY 26:00:30 hours GMT), the wing sections had deployed 100 percent, thus ending an abnormal storage period of 24 days in a partially deployed configuration.

Deployment allowed the full power generating capability on that wing or approximately one-half of the total SAS design capability of each SAG.

The original 2-wing solar array subsystem was required to deliver an average available power to the AM/OWS interface of not less than 10,496 watts, within a voltage range of 51 to 125 Vdc, integrated over the sunlight portion of the orbit at the end of mission. This power was required to be distributed among eight (8) individual Solar Array Group (SAG) sources with an available average of not less than 1,312 watts each. With the loss of Wing 2, the power was reduced to 5,248 watts total and 656 watts for each half-SAG source. The prelaunch prediction for SAS performance degradation, from all causes, was 8.3% at the end of mission. The minimum required average of 5,723 watts total and 715 watts from each SAG at the beginning of the mission was derived. The voltage requirement was not affected by the loss of Wing 2. SAS performance was analyzed for several orbits following deployment. Array performance was analyzed for an average array temperature of $+145^{\circ}F$ ($335^{\circ}K$) and Figure 7.4 shows an available average array power of between 6,500 watts and 7,050 watts. The apparent increase in power, over the period of the mission, occurred for two reasons; (1) solar flux increased from a minimum (Aphelion) near the beginning of the mission, to a maximum (Perihelion) at approximately DAY 237, and (2) no measurable performance degradation was detected. Solar Array Group (SAG) voltage and current data was evaluated for solar inertial orbits at beta angles from 0° to 73.5°. At low beta angles, 1) the SAS saw the sun approximately 61% of the time, 2) the highest Depth of Discharge (DOD) (for solar inertial attitudes) on the PCG

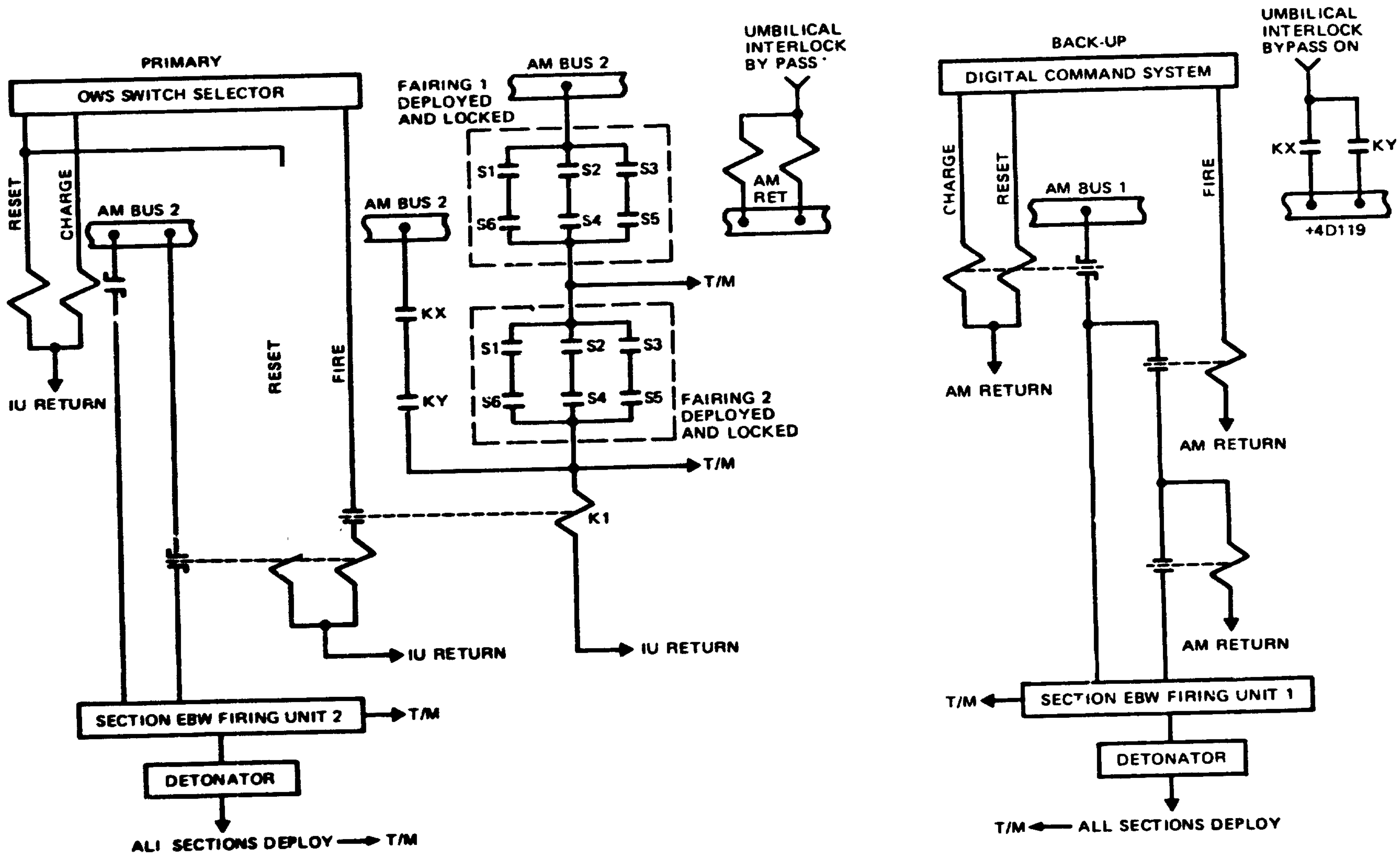


Figure 7.3 OWS Solar Array Wing Section Deployment Circuits (Primary and Back-up)

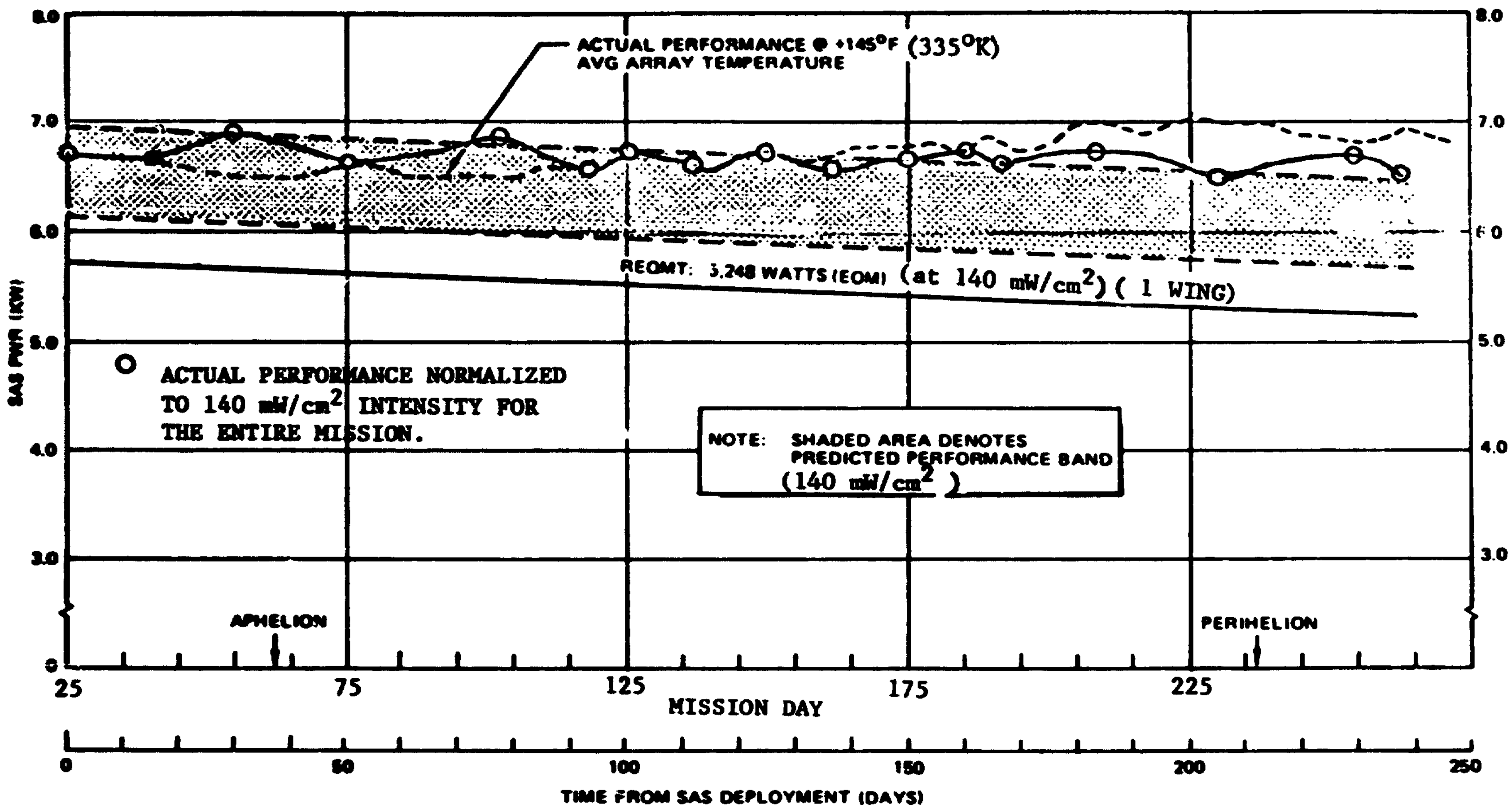


Figure 7.4 OWS Solar Array Performance Comparison (Requirement/Predicted/Actual)

batteries occurred, thus the SAS operated at peak power for several minutes. At beta angles above 69.5°, continuous sunlight orbits occurred, and battery charge/discharge cycles did not occur; hence the system did not operate at peak power, and only small variations were seen in SAS voltage and current.

Figures 7.5 through 7.7 show SAG voltage and current profiles for DAYs 26, 42, and 206. Data for DAY 42 (Figure 7.6) is included to illustrate high beta, continuous sunlight, SAG characteristics. Figure 7.7 for DAY 206 shows voltage and current profiles during one orbit of peak power operation after EREP 11.

Analysis of data for DAY 266, near the end of SL-4, revealed the fact that voltages and currents for each of the groups were very similar to those shown for DAY 26.

In solar inertial vehicle orientation, shadowing from the ATM solar array resulted in the loss of less than one module from SAG 5, less than two (2) modules from SAG 6, and one full (1) module from SAG 8. Only one or two cell strings were lost from SAG 5. For SAG 6, one module was always shadowed and up to two additional strings were shadowed on the second module. The variation in the number of strings shadowed was a result of small variations from true solar inertial vehicle orientation, and appeared to verify the $\pm$ 0.5 degree predicted vehicle control accuracy.

The lower current in SAG 4 on Figure 7.5a was due to an anomaly in the current measurement which was postulated to have resulted from SAG 4 return shorting when Wing 2 was lost. If the current for SAG 4 was as low as indicated, the battery of PCG 4 would take much longer to recharge than the other batteries. There was no indication that Battery 4 had taken longer for recharge than any other battery supplied by a 15 module SAG.

The events of an orbit can be followed on Figure 7.5. The data begins near the end of the sunlight portion of an orbit. As the solar array went into night, the current dropped to zero, and the voltage dropped to the AM PCG battery voltage. During this period, the batteries provided the power to the loads and their depth of discharge depended upon the load and the duration of the shadowed portion of the orbit. When the arrays came into sunlight, they were cold (see Figure 7.9), and the voltages were at their peak values and decreased as the array warmed up. The current was high because of the increased loads while the batteries were recharging.

When the batteries approached full charge, the charge rate decreased resulting in a drop in current and a rise in voltage. After

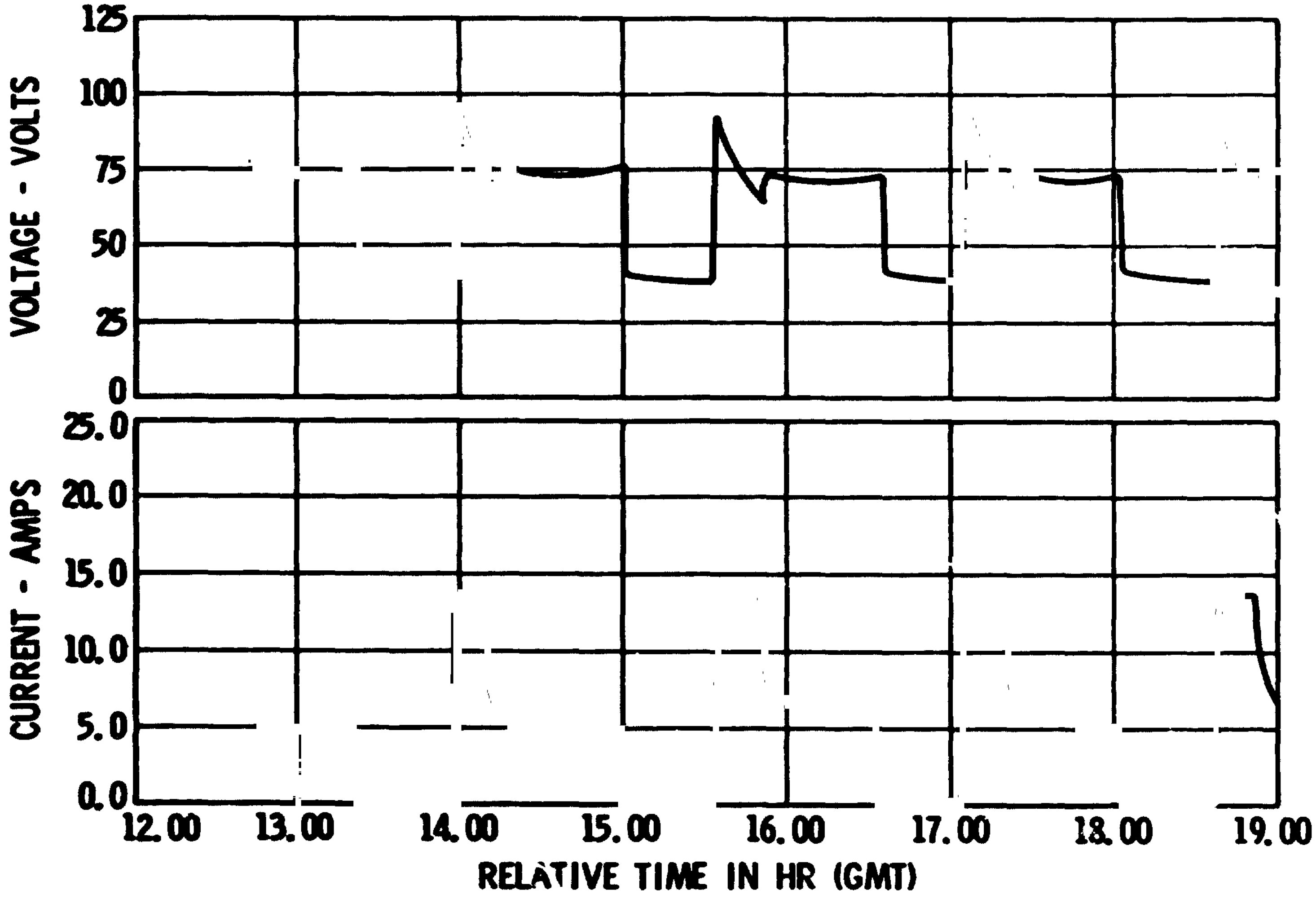


Figure 7.5a Solar Array Group Current and Voltage Profiles for DAY 26 (SAGs 1,2)

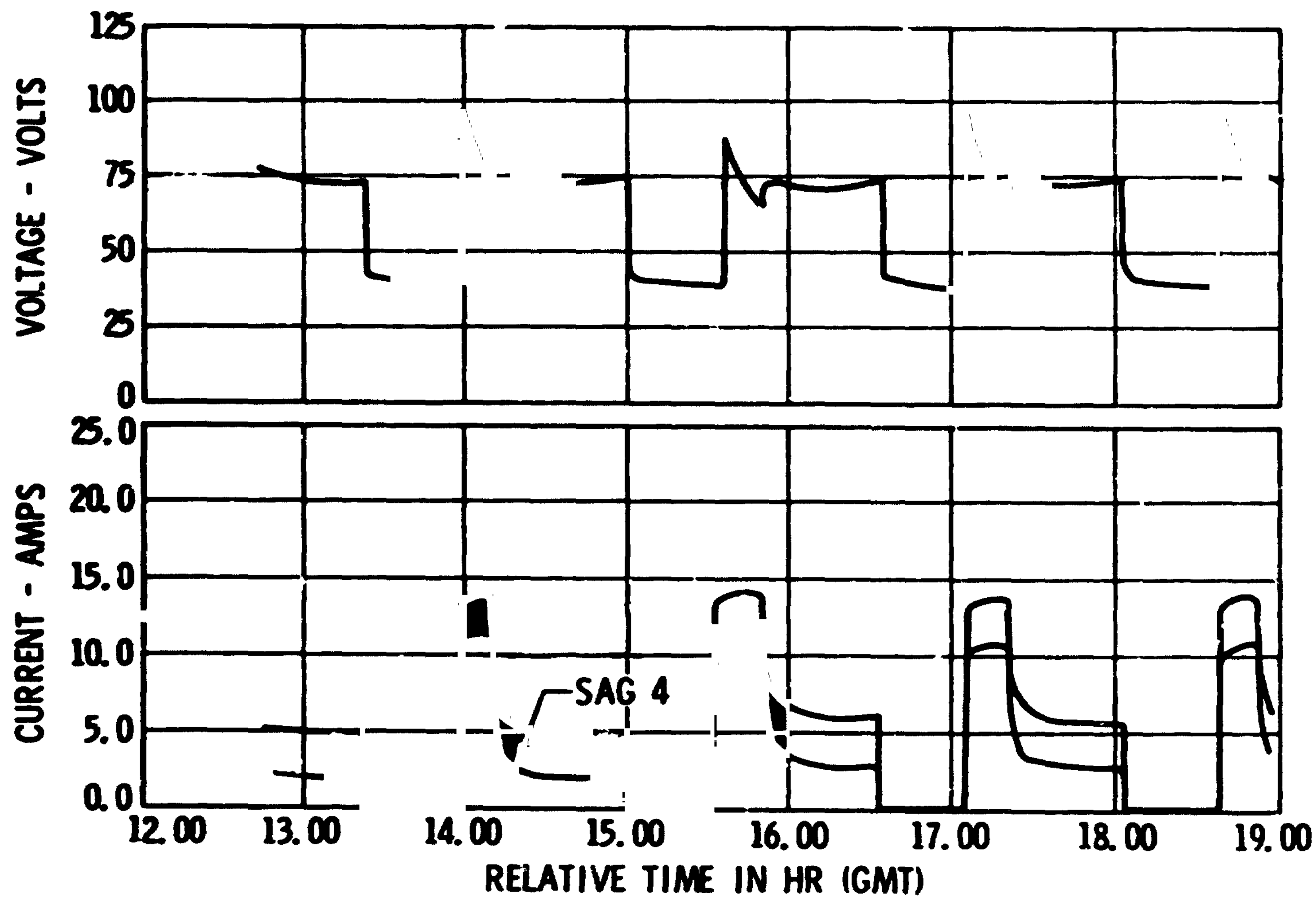


Figure 7.5b Solar Array Group Current and Voltage Profiles for DAY 26 (SAGs 3,4)

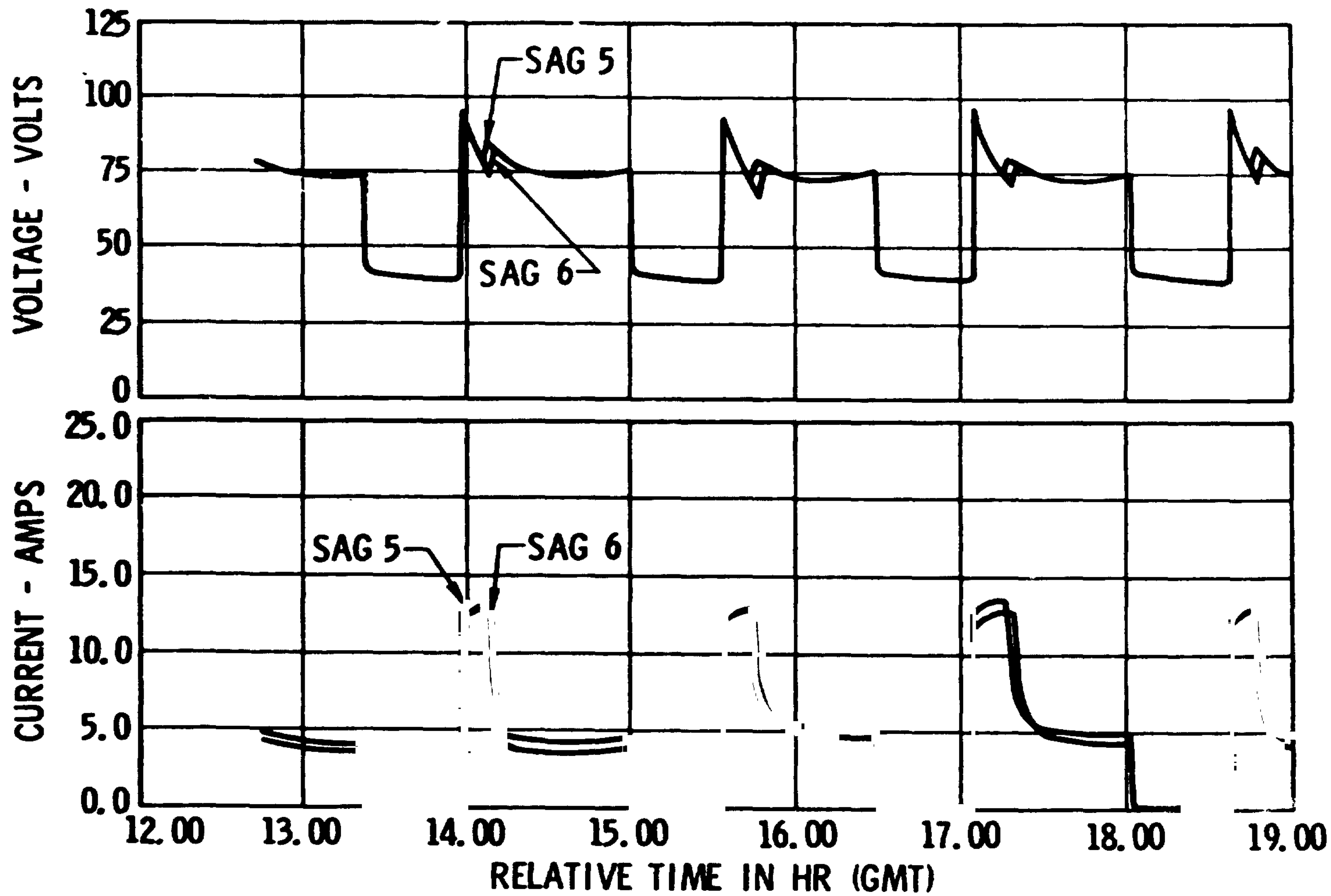


Figure 7.5c Solar Array Group Current and Voltage Profiles for DAY 26 (SAGs 5,6)

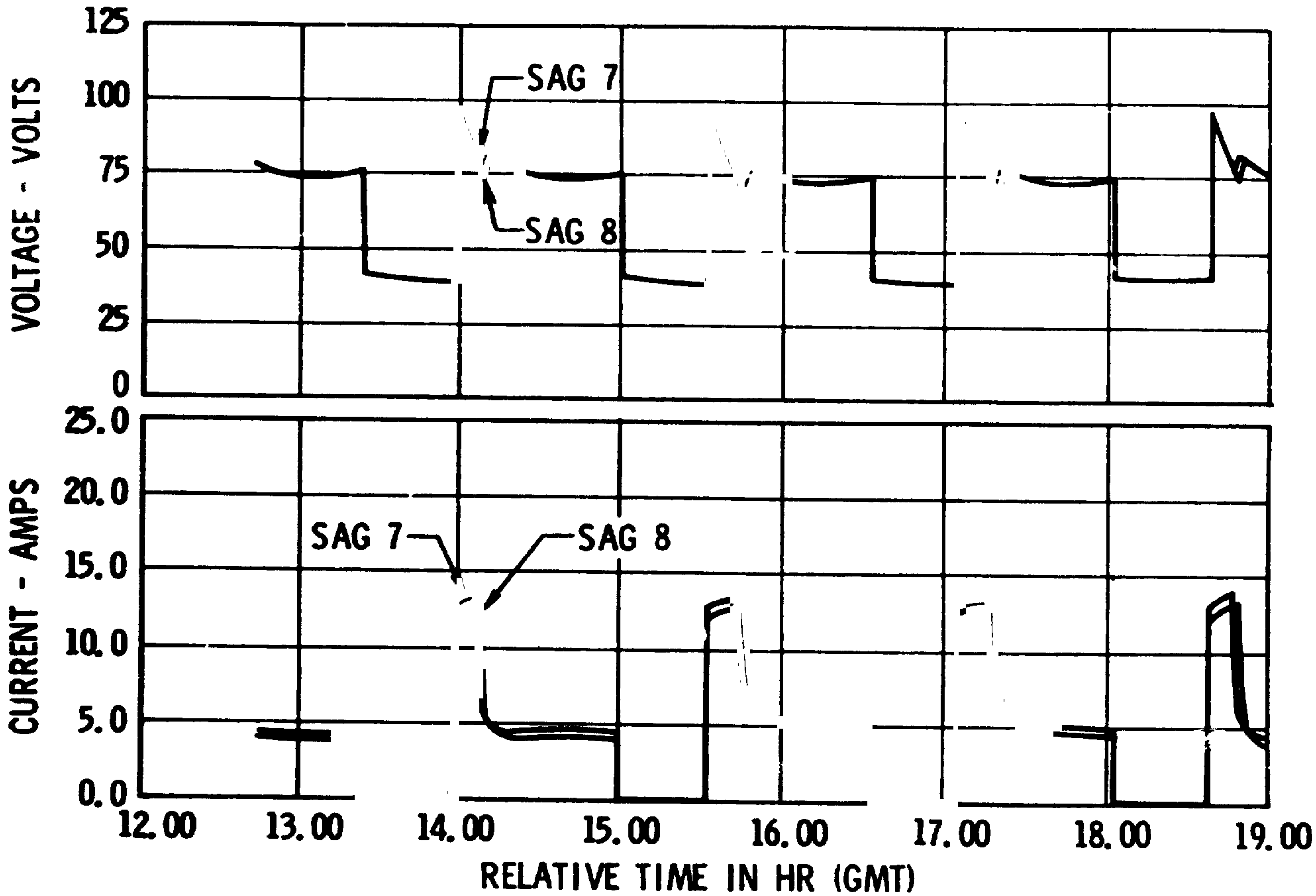


Figure 7.5d Solar Array Group Current and Voltage Profiles for DAY 26 (SAGs 7,8)

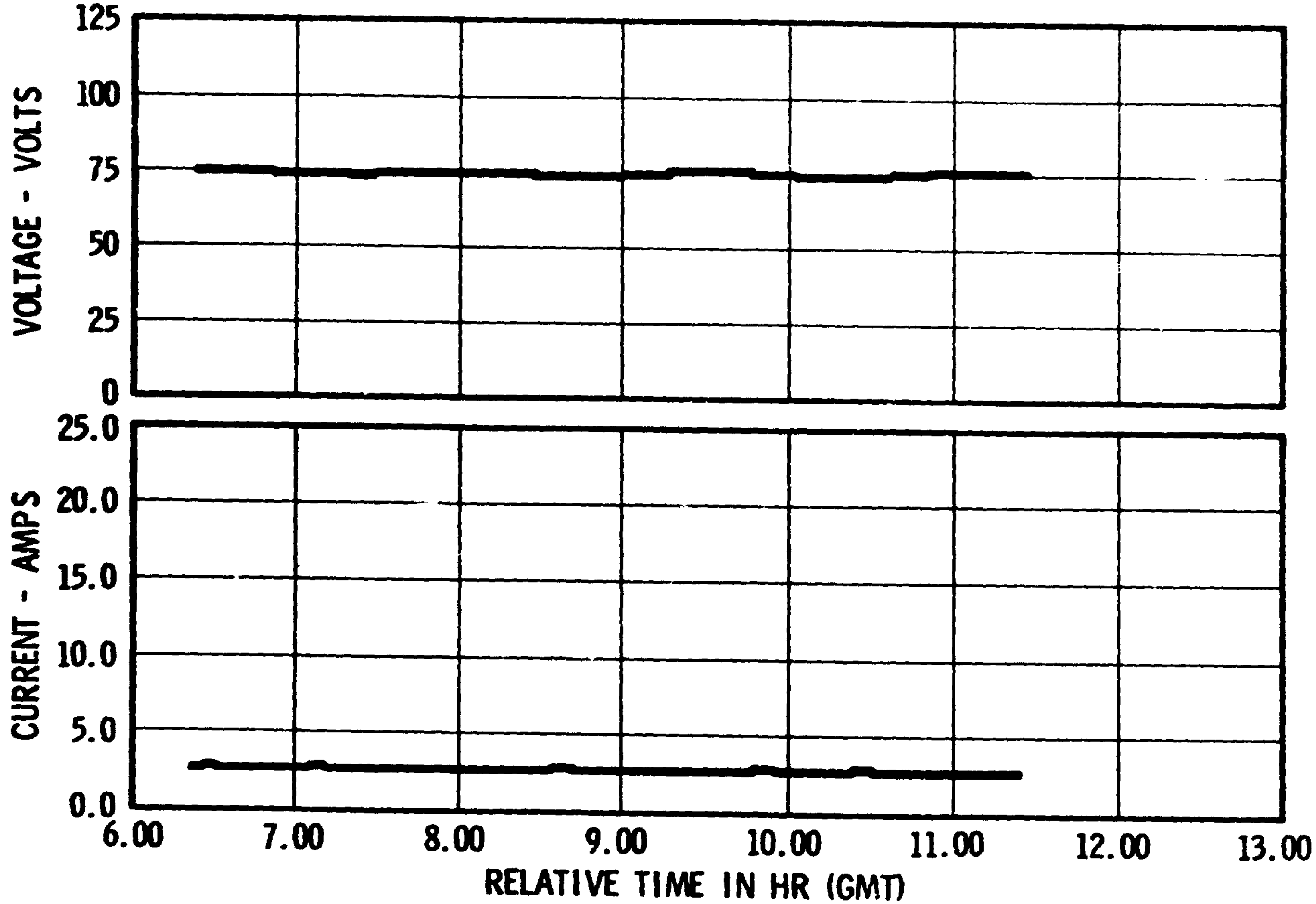
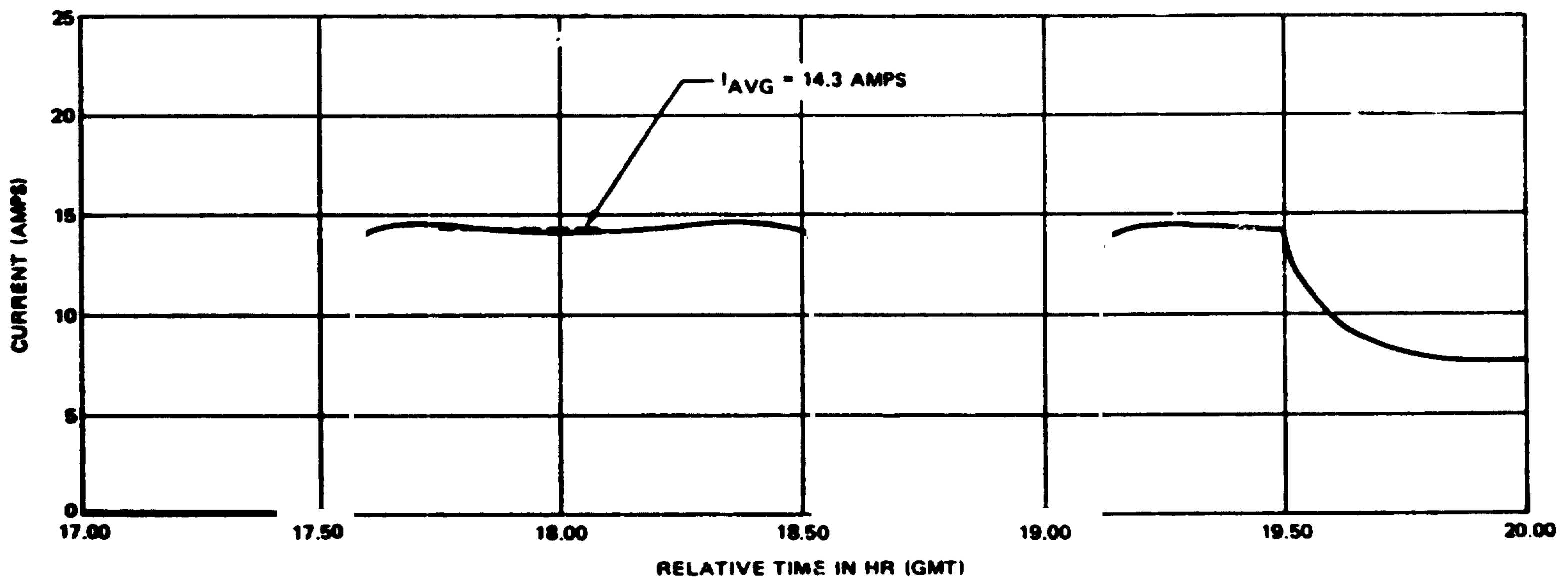
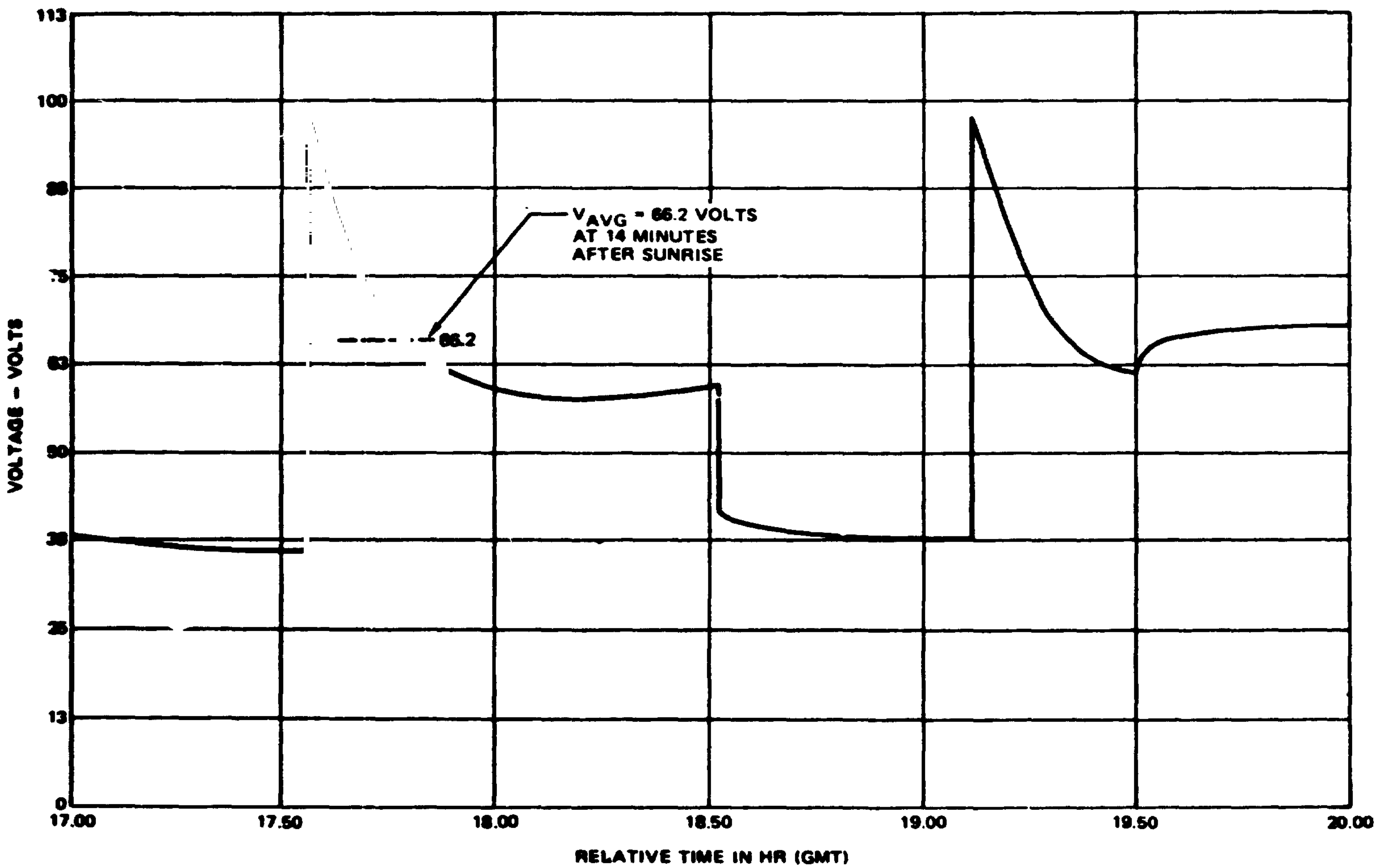


Figure 7.6 Solar Array Group Current and Voltage Profiles for DAY 42 (Beta >69°)



NOTE: Peak Power Tracking for one orbit was followed by recovery on the next orbit.

Figure 7.7a SAG 1 Current Immediately After EREP Pass 11 Which Discharged Batteries to Unusually Low State-of-Charge.



NOTE: Peak Power Tracking for one orbit was followed by recovery on the next orbit.

Figure 7.7b SAG 1 Voltage Immediately After EREP Pass 11 Which Discharged Batteries to Unusually Low State-of-Charge.

the batteries were fully charged, the current remained nearly constant at the lower values shown and the voltage continued to vary as a function of temperature with a slight rise in voltage prior to the end of sunlight portions of the orbit corresponding to the small decrease in temperature that occurred.

One slice of data for DAY 26 was analyzed in detail when all SAGs were operating near maximum power, that is, when the combination of battery charging and bus loads present the maximum demand and the operating point of the SAS was controlled by the PCG peak power tracker. The data slice was at 6.5 minutes after sunrise. At this time, the average transducer temperature was determined to be 21.8°F. A delta-T of 32°F was added to this value to obtain the solar cell temperature of 53.8°F. The ΔT correction factor is a function of (1) time from sunrise, and (2) beta angle. The voltage and current for each SAG was determined at this time slice and plotted against SAG prediction curves in Figures 7.8a through 7.8c. These figures represent the performance predictions for 13, 14, and 15 module SAGs. In all cases, except for SAG 4, the performance exceeded the predicted values. The higher actual SAG performance values were attributable, in part, to (1) reflected energy from the gold tank surface, (2) less shadowing than predicted, and (3) SAGs 5 through 8 were below the average array temperature because they were primarily located on the outboard wing section. Analysis of PCG input and output power values and battery charge current measurements indicated normal PCG 4 operation, and that SAG 4 was producing power comparable to the other SAGs having no shadowed modules. For purposes of SAS performance evaluation, SAG 4 current was assumed to be equal to the average of SAGs 1, 2, and 3 currents. Using this method of evaluation, it was concluded that SAG 4 current also exceeded the predicted value. Average array power, at +145°F (335°K), was determined to be 6700 watts.

SAG 1 voltage and current profiles, shown on Figure 7.6 for the 73.5° beta orbit on DAY 42, are for a Beta of 69.5°. SAG voltage was fairly constant at 75 volts and SAG current measured 2 to 3 amps. These values were consistent with the constant array temperature at high beta angles and the fact that the PCG batteries demanded only trickle charge current at this time.

Figure 7.7 shows the voltage and current performance of SAG 1 for DAY 206, beta angle = -9°, after the EREP No. 11 maneuver to Z-LV (Z-axis Local Vertical) which was concluded at GMT 1634.

Battery Depth of Discharge (DOD) was great enough following the maneuver to cause all SAGs/PCGs to remain in the peak power tracking mode for one entire solar inertial orbit. Array performance at about 5 minutes after sunrise was analyzed. The average temperature transducer measurement was +12.3°F (262°K), the delta-T correction

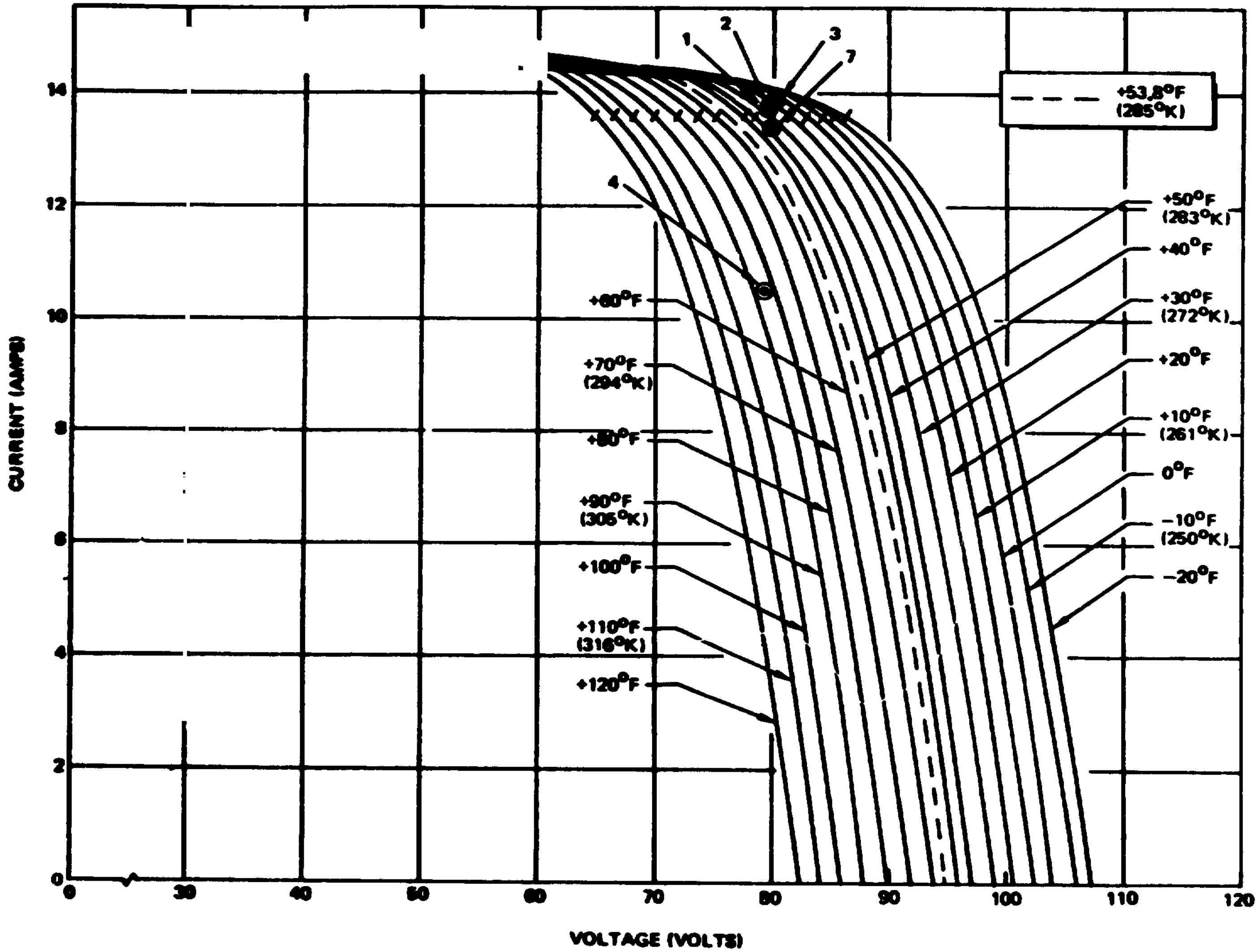


Figure 7.8a SAG V-I Characteristics at Various Temperatures Showing the Maximum Power Point for SAGs 1,2,3,4, and 7 on DAY 26 (15 Modules)

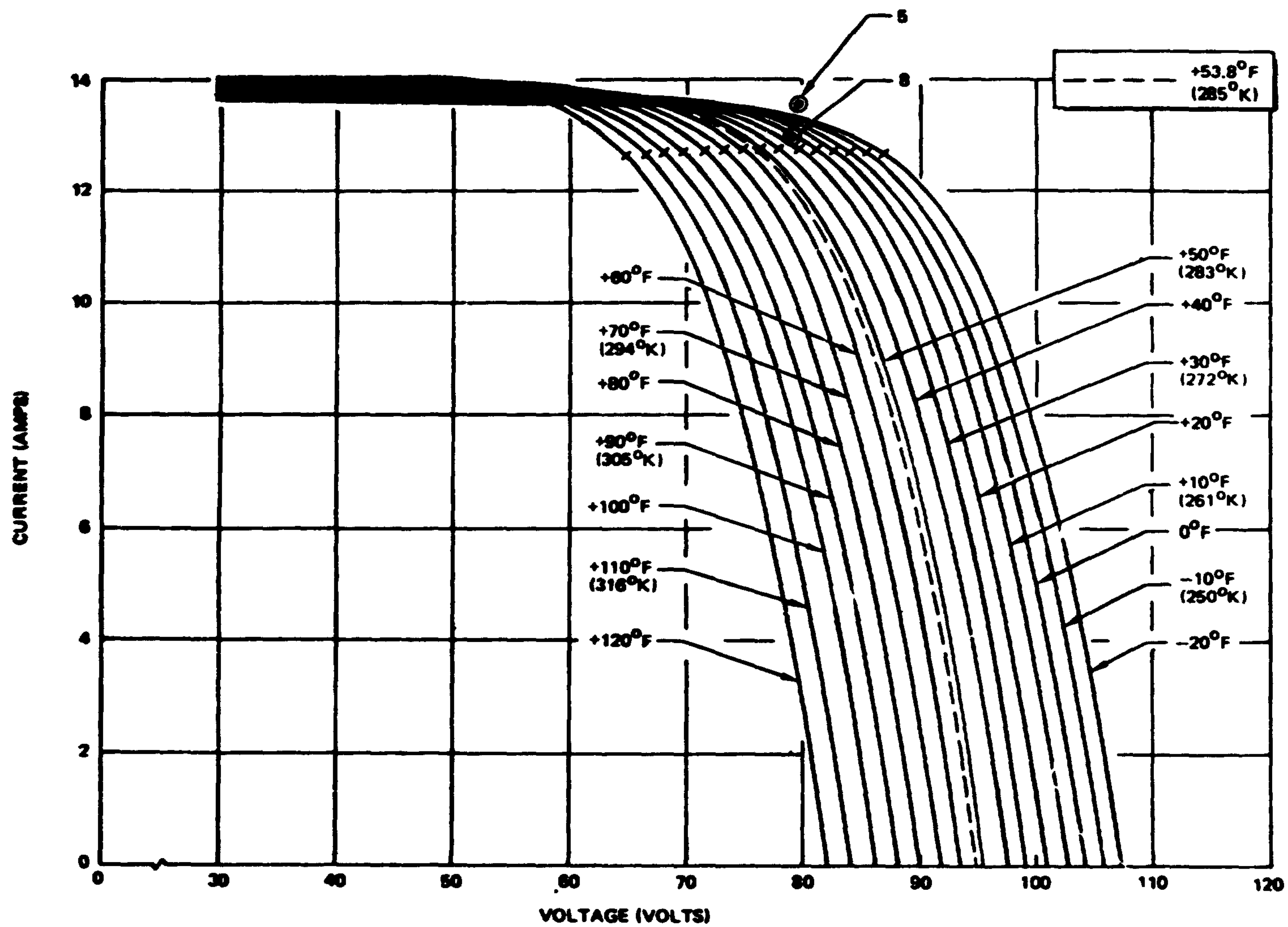


Figure 7.8b SAG V-I Characteristics at Various Temperatures Showing the Maximum Power Points for SAGs 5 and 8 on DAY 26 (14 Modules)

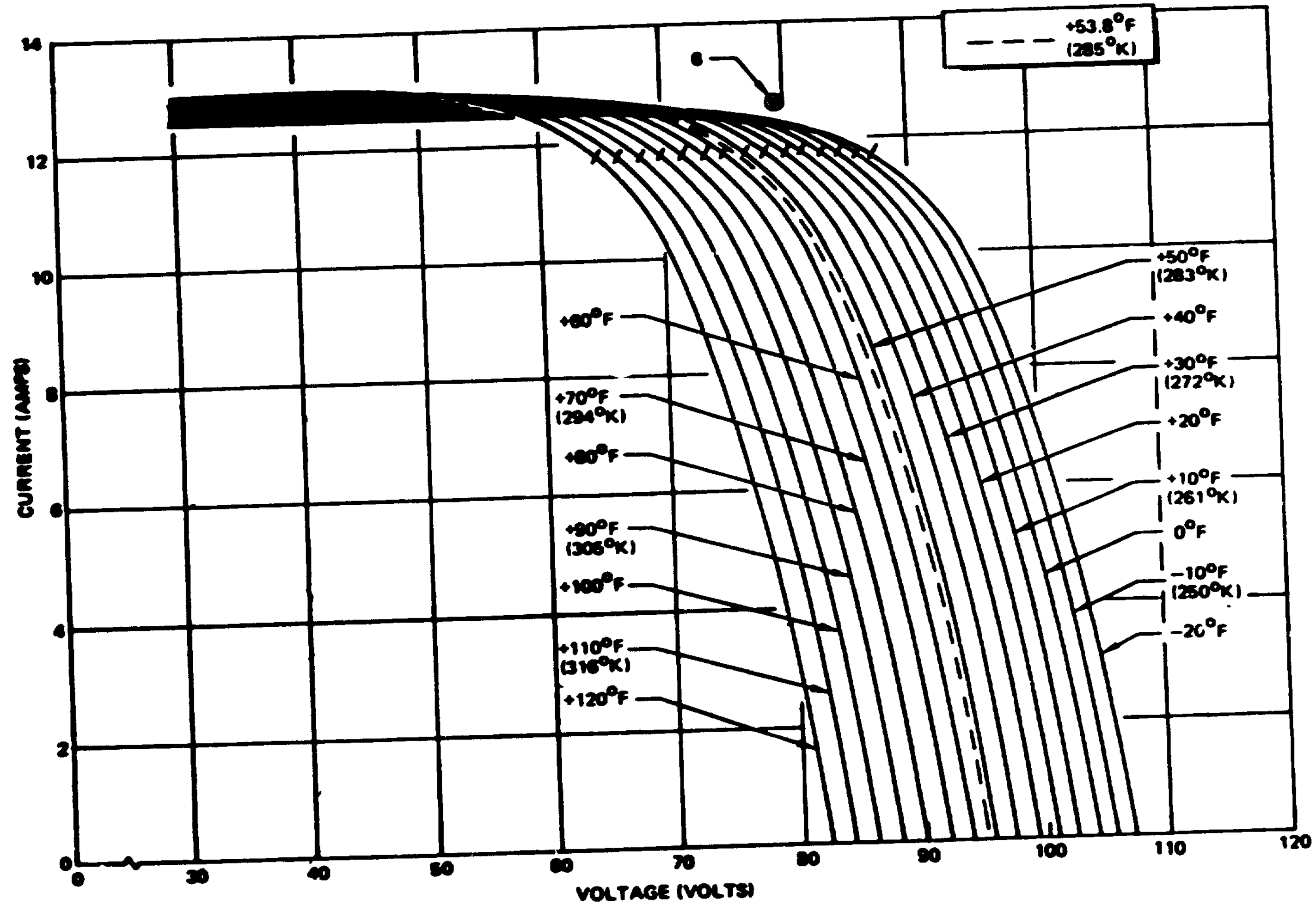


Figure 7.8c SAG V-I Characteristics at Various Temperatures Showing the Maximum Power Points for SAG 6 on DAY 26 (13 Modules)

factor was determined to be +32°F (18°K), and the resulting average array temperature was +44.3°F (280°K). Average SAS power was found to be 6970 watts at +145°F (335°K).

As a verification of the above method of determining average array power for instantaneous values of SAG voltage, current, and temperature, continuous (taped) data was analyzed for SAG 1. Voltage, current, and temperature data (Figures 7.7, and 7.12, respectively) were integrated and average values of each were determined. Using this technique the resulting average array power was found to be 6940 watts which correlates within less than 0.5% with the 6970 watts obtained using the instantaneous or single data slice method.

Voltage and current performance characteristics for SAGs 1 through 8 on DAY 266, beta 0°, are the same as those recorded on DAY 26, with the exception of time in peak power operation. Calculated average array performance, at +145°F (335°K), was 6895 watts.

The calculation of average and maximum available array power values for each SAG were recorded on a daily basis. In both cases, the variation since SAS deployment was well within the accuracy of the measurements involved, demonstrating the assertion that no SAS performance degradation trend was detectable throughout the mission.

This was attributed to the fact that the orbital environment encountered by the SAS was very nominal, and in particular, the extremes of thermal environment were less severe than those assumed in preflight analyses and testing. Additionally, there was no measurable degradation of solar panel thermal control surfaces.

The power margin at the end of mission was also a result of some conservatism in original performance predictions.

> The early program concern over the discrepancy between the AM power requirement and predicted array performance resulted in concentrated efforts to make the best possible use of available array area and to ensure providing a minimum of 51 volts at the AM/OWS interface.
>
> Shadowing analyses considered 17 out of 240 modules would be shadowed for entire orbits (5° TACS control). In reality, only 3 equivalent modules (of 120 Wing 1 modules) were shadowed during CMG control (± 0.5°).
>
> Power calculations assumed 3-sigma maximum instantaneous values of heat flux for entire orbits. In actuality, the effects of the random behavior of earth IR and albedo are not well known.

The assumption of an eight degree mis-orientation error existing continuously between the array and the sun was overly conservative.

Solar module pre-mission performance capability was higher than predicted because of higher average solar cell output (256 mA vs. 248 mA) and lower manufacturing losses.

SAS wiring was sized assuming worst case high temperatures which resulted in less voltage drop than predicted.

(a) Thermal. With the loss of Wing 2, the operating temperature of the SAS was determined from the outputs of ten (10) temperature transducers on Wing 1, corrected as a function of beta angle and elapsed time since orbital sunrise. The solar panel transducer temperatures were cyclic with each orbit with the maximum and minimum temperature dependent upon the beta angle of the orbit and the orbital thermal environment.

As the beta angle increased, time in the earth's shadow decreased and total sunlight orbits occurred for beta angles above approximately 69.5°. Figures 7.9 through 7.12 show typical SAS temperature transducer profiles for the following days.

Figure	7.9	7.10	7.11	7.12
DAY	26	42	206	266
Beta	+10°	+73.5°	-9°	0

Maximum and minimum temperatures of the 10 transducers are plotted.

Comparison of actual temperature profiles with predicted profiles showed good correlation. Some differences did exist in the parameters of the maximum temperature and the temperature gradients across the wing, but these did not significantly affect performance.

The predicted maximum temperature, occurring near orbital noon, was lower than the measured value, since it was based on the assumption that the SAS would be operating at peak power continuously in sunlight.

In reality, peak power operation ended when the batteries approached full charge, and this generally occurred in the first 15 minutes of sunlight in a solar inertial orbit. When operating below peak power, the array efficiency dropped and self heating increased.

The larger gradient of the actual temperatures was a result of the loss of the meteoroid shield. The meteoroid shield in the vicinity of Wing 1 was painted black and had a low reflectivity. The loss of

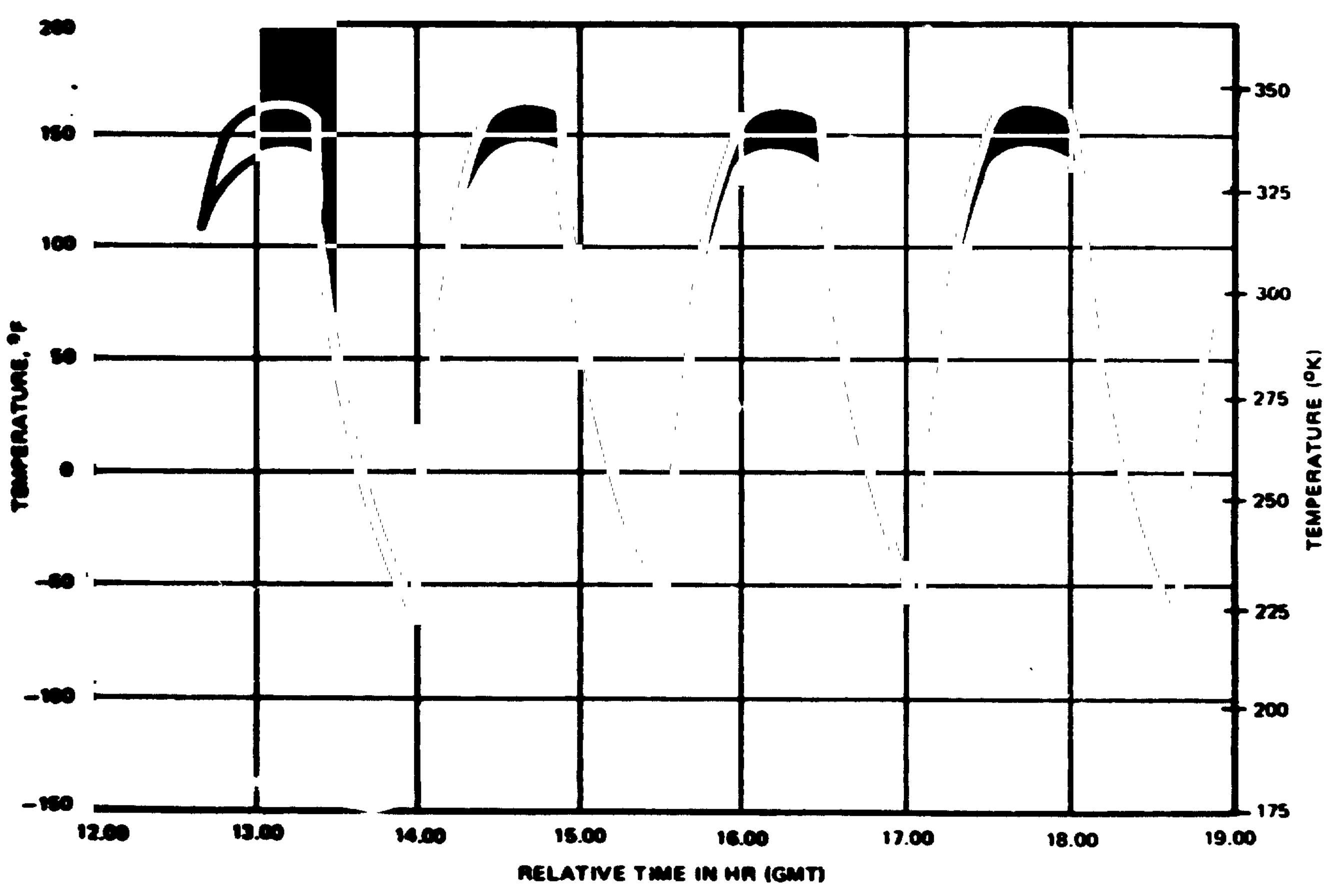


Figure 7.9 SAS Transducer Thermal Profile for DAY 26 (Beta =10^{o})

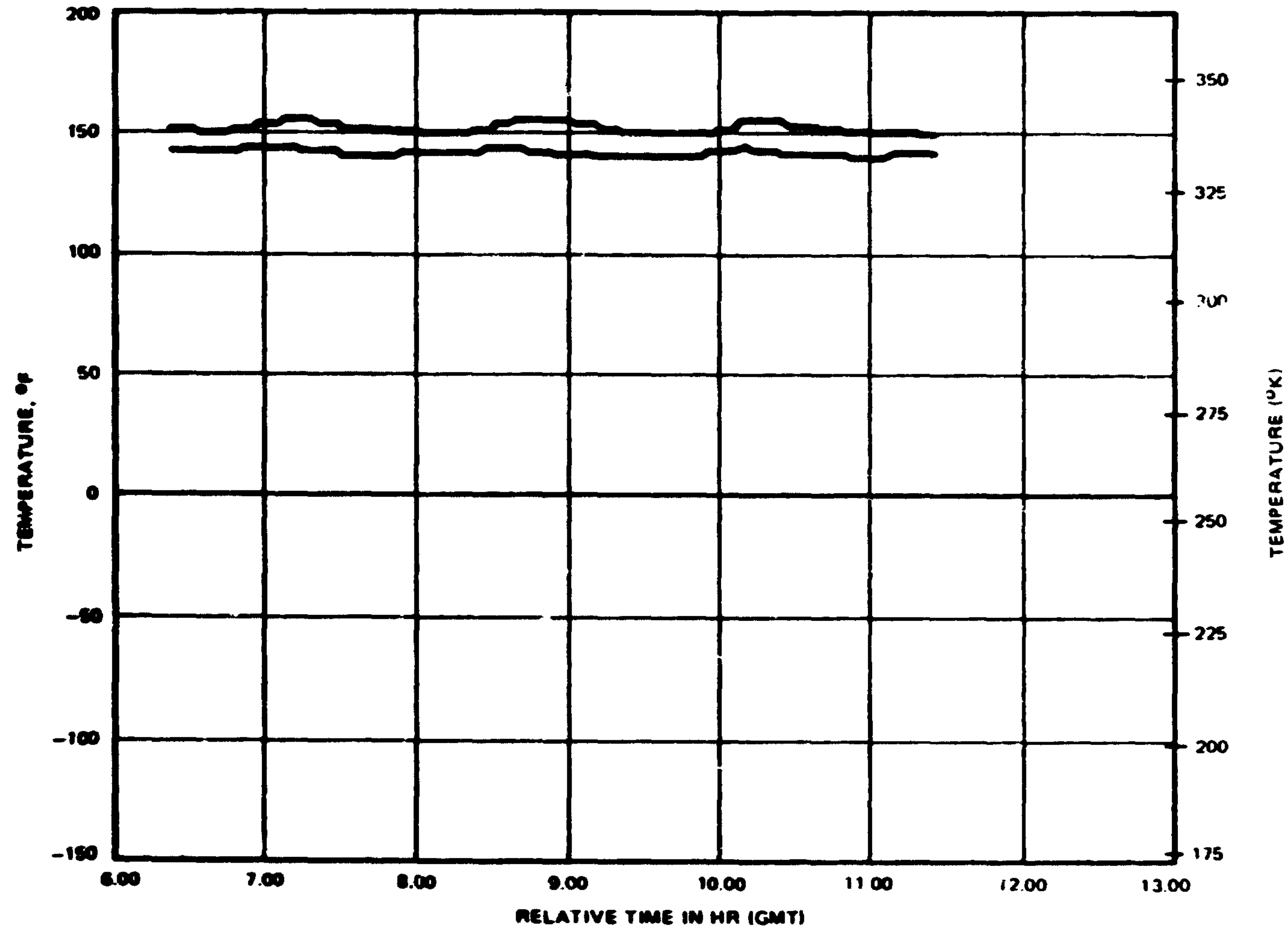


Figure 7.10 SAS Transducer Thermal Profile for DAY 42 (Beta = 73.5°)

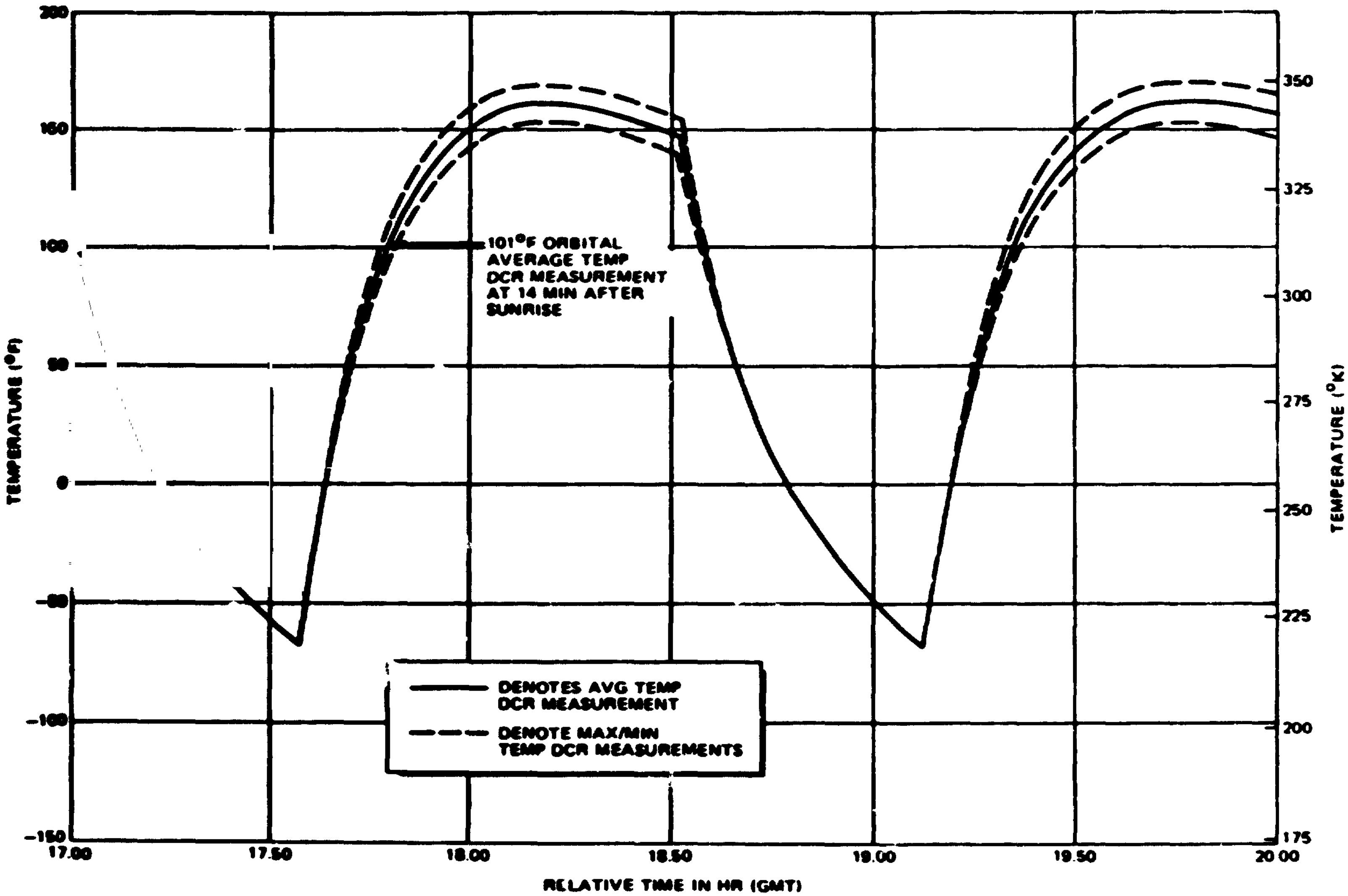
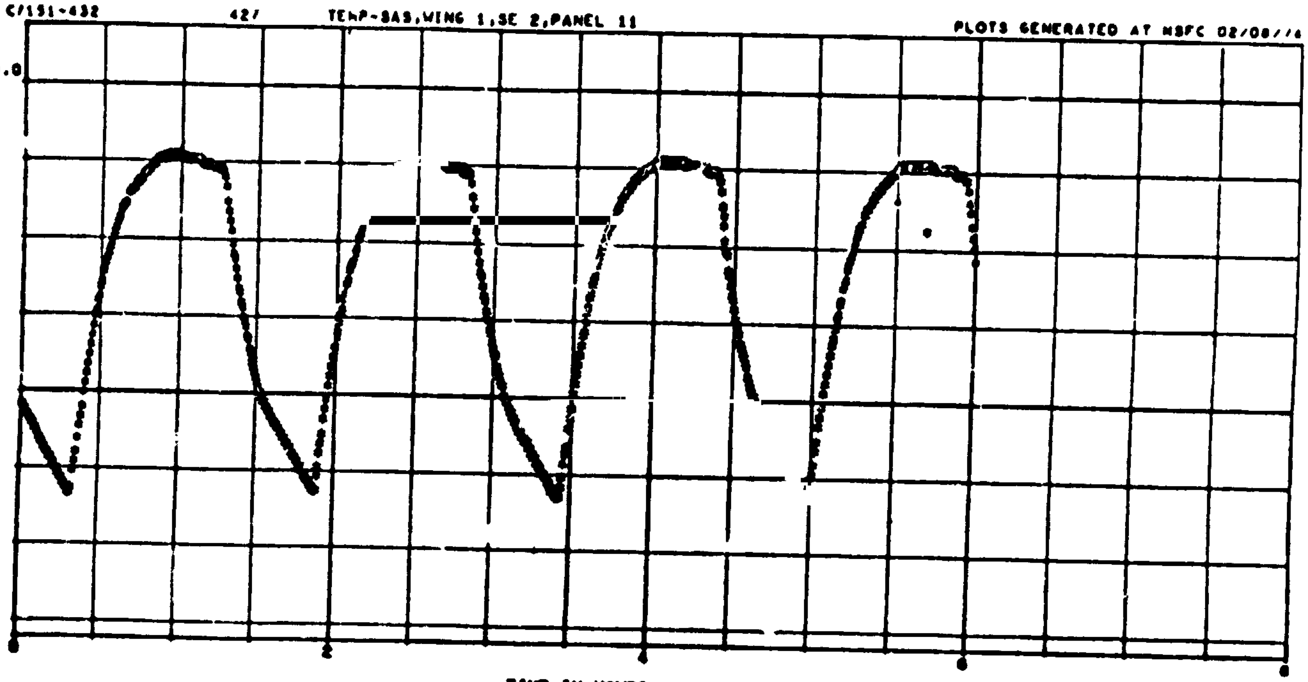


Figure 7.11 SAS Transducer Thermal Profile for DAY 206 (Beta = -9^{o})



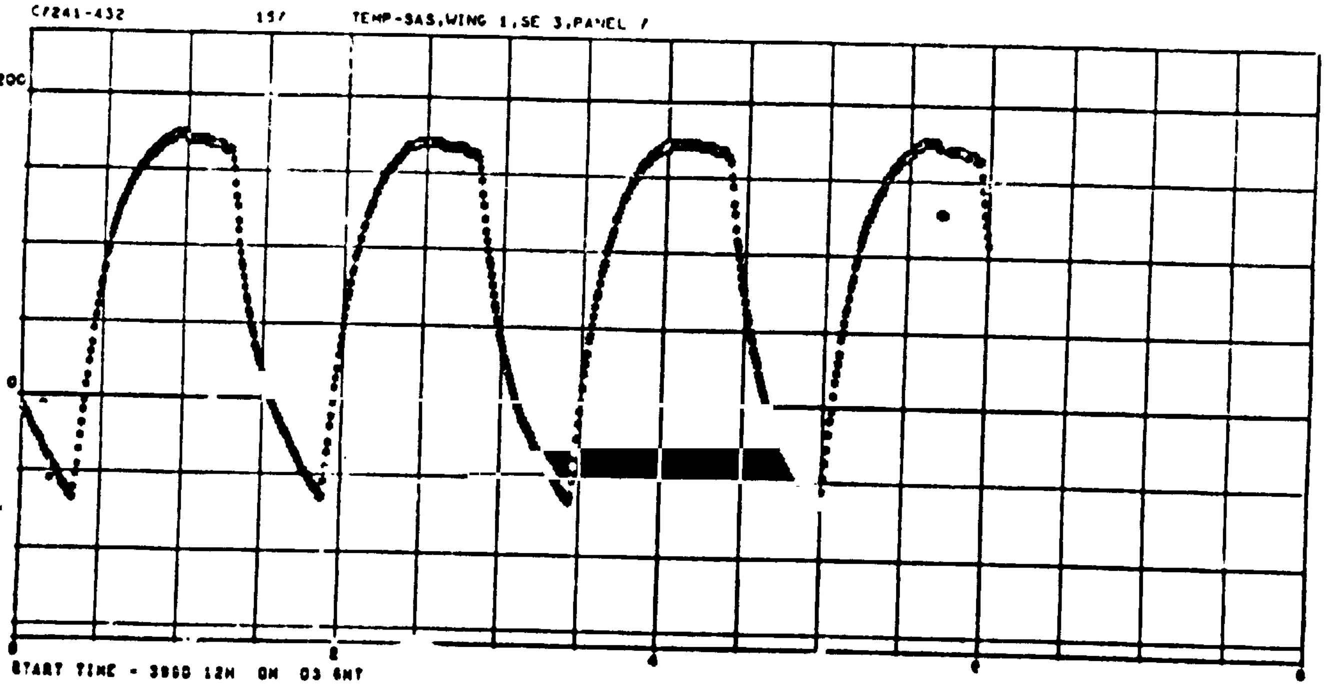


Figure , ` SAS Transducer Thermal Profile for DAY 266 (Beta = 0^0)

the shield exposed the high reflectivity gold surface and resulted in increased albedo reflection from the OWS tank, and in the area where the parasol did not shade the OWS tank, direct solar reflection from the tank to the SAS.

The temperature transducer measurement history indicated high and low temperature, maximum and minimum, transducer readings at orbital noon and prior to sunrise. A trend toward slightly warmer temperatures, at a given beta angle, was attributed to increased solar intensity as the mission progressed; hence, it appeared that no measurable degradation of solar panel thermal characteristics had taken place.

(2) Power Conditioners. Eight independent power conditioners regulated power from the solar array to supply power to assigned loads and to charge the storage batteries during the daylight periods. Conditioned power was applied to either of two main buses by switch control. Major components of each power conditioner were: a charger, battery, and voltage regulator.

(a) Charger. The battery charger (Figure 7.13) received power from the solar array and supplied it to the bus regulator primarily to satisfy load demands and secondarily to charge the battery (Figure 7.14). A peak power tracker unit restricted the charger output so that the solar array power requirement would not exceed the maximum power point, thereby preventing overloading of the arrays. An ampere-hour meter controlled battery charging by measuring the amount of current supplied by the battery and ensured that a like amount was replaced.

The battery chargers performed satisfactorily both before and after the deployment of solar array wing 1. The battery chargers, in power conditioners 5, 6, and 7 operated with dual low power solar array inputs to charge their respective batteries to 100 percent. Solar Array currents during the charging of these batteries (5 through 8) were between 0.4 and 1.2 amperes, prior to Wing 1 deployment. These current levels were significantly below the desired range of operation for the battery chargers in any planned mode.

The other four batteries (1 - 4) could not be charged because the power available, from the imposed dual solar array group combinations for these batteries, was insufficient to operate the battery chargers. Another result of the low solar array power was that flight telemetered data, on battery chargers 1, 3, 4, and 8, and possibly the other battery chargers, verified that they experienced an oscillating input caused by the repetitive collapse and recovery of the solar array output characteristic. The array voltage would rise to the point at which the battery charger bias circuits would

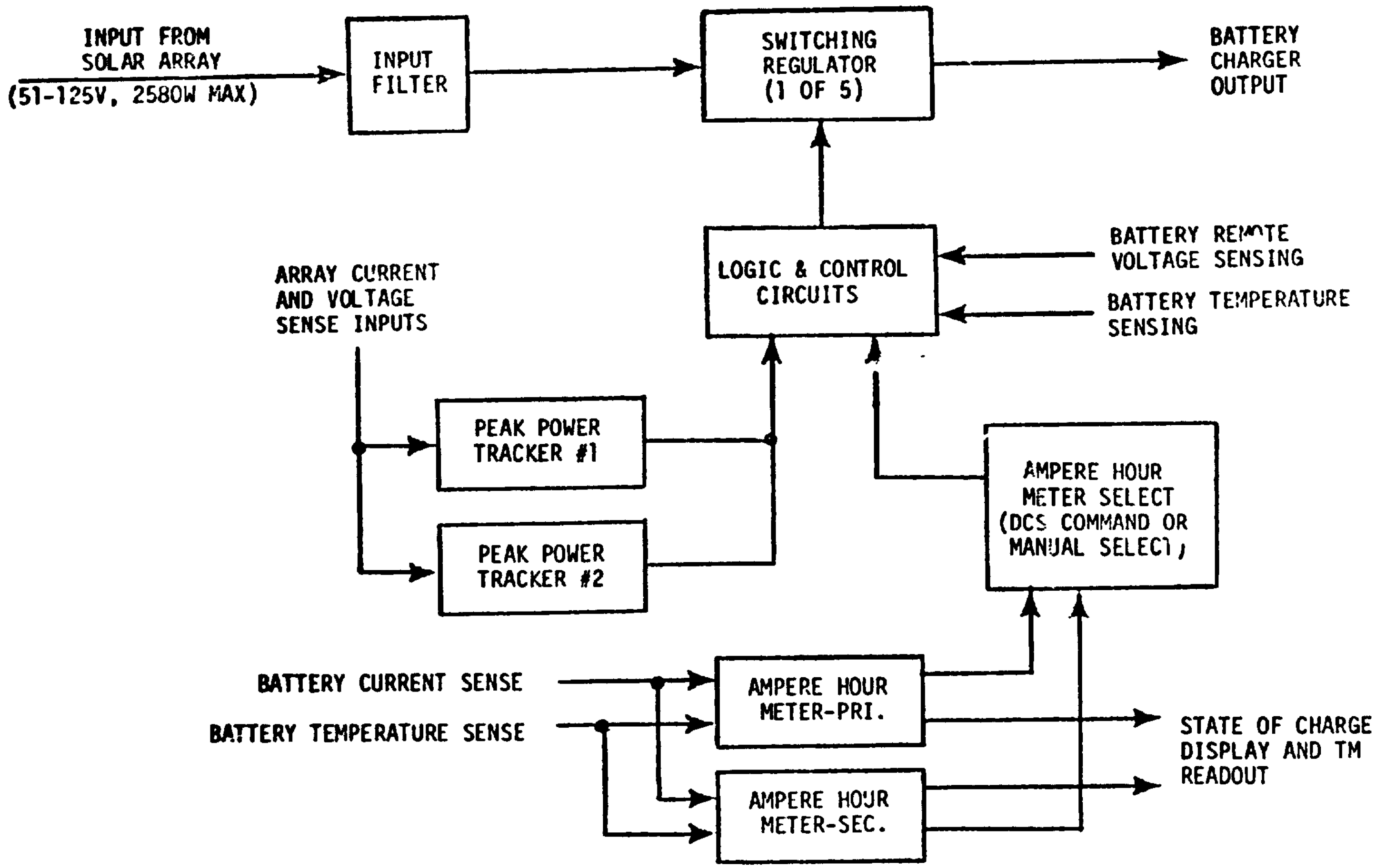


Figure 7.13 Battery Charger Functional Block Diagram

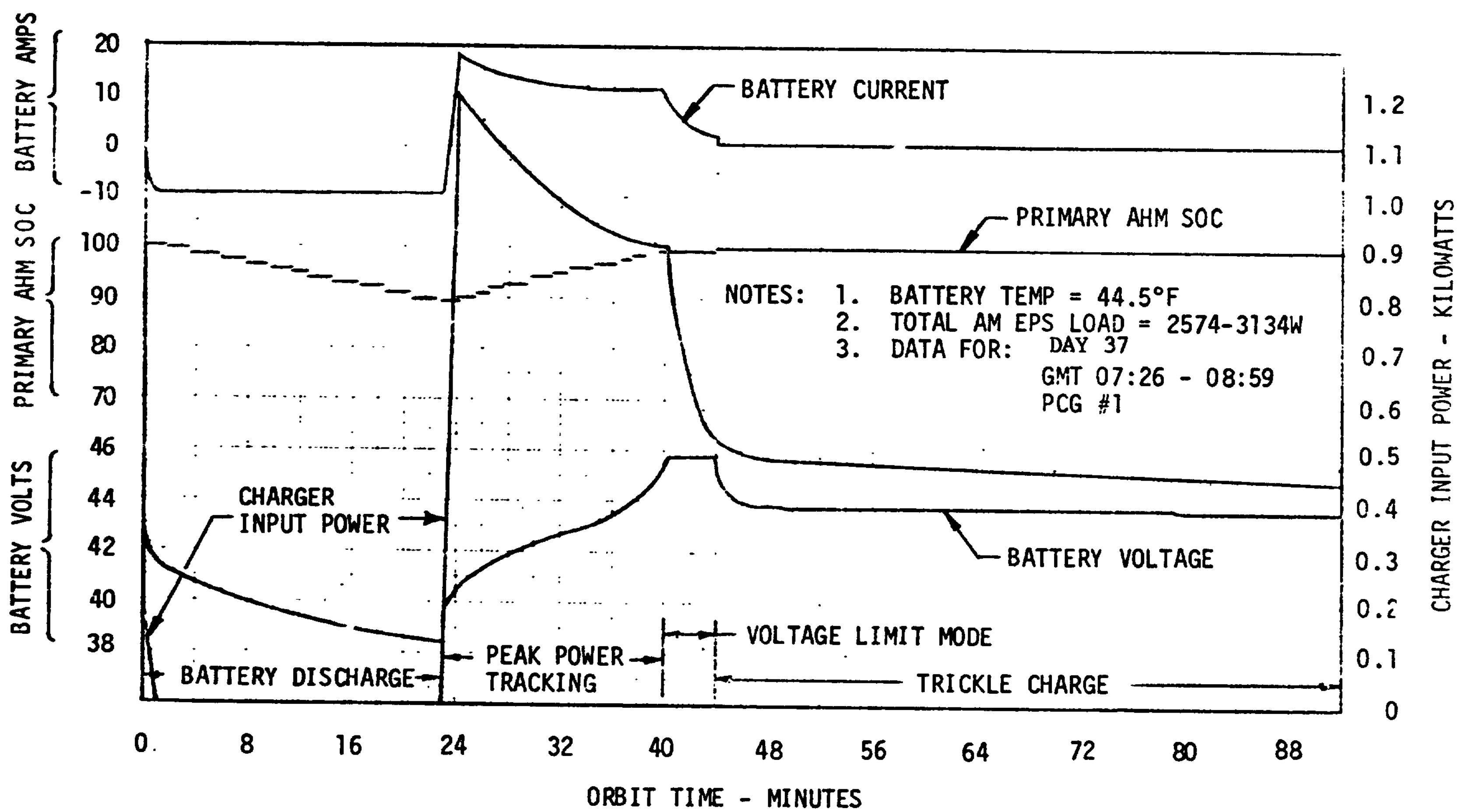


Figure 7.14 Typical PCG Orbital Parameter Variations

turn on. The current drawn by the bias circuits, however, would pull down the solar array voltage to such a level that, because of the low solar array power, the circuits would turn off again. At this point, the array voltage would recover to its original level, and the cycle would repeat again. Analysis of the battery charger circuits, however, indicated that this condition should not have caused any problems. As a safety factor, however, the charger switch was placed in the bypass position, so that the solar array output was removed from the battery charger input. This was maintained for most of that period in the mission.

Another abnormal condition occurred when the Amp-Hour (A-H) meters for PCG #8 were reset to 0% on DAY 14. This resulted when A-H integrator CB #8, on STS panel 201, was inadvertently opened by crew action. Normally, the reset to 0% would not have resulted from this action, since each A-H meter is powered from redundant sources through an A-H integrator CB and a battery control CB. However, all battery control CBs were open during this period to prevent the A-H meter circuits from discharging the batteries while the batteries could not be recharged. After solar array power became available, the A-H meters for #8 were returned to synchronization with the actual battery SOC and they operated normally thereafter.

Each battery charger conditioned its associated solar array group input so that peak power was extracted upon demand during initial battery charging, battery voltage was limited as determined by battery temperature during the voltage limit charge mode, and battery current was regulated when the battery-charger-controlling ampere-hour meter indicated a 100 percent battery state of charge. Figure 7.14 illustrates the typical operation of a power conditioner for one charge-discharge cycle after the workshop solar array wing deployment through to the all-Sun position attained on DAY 39.

<u>1</u> Peak Power Tracking. Peak power tracking was experienced from the beginning of each sunlight period until the battery was fully charged. Available solar array power was maximum at sunrise, and it gradually decreased following sunrise as the solar array group temperature increased. The peak power tracking portion of the charger input power curve in shown in Figure 7.14. The operational diagram of the charger peak power tracker, Figure 7.15, shows how it extracted maximum power from the solar array group immediately upon sunrise and then decreased its demand as the available solar array group decreased. As shown in Figure 7.15, the peak power tracker closely followed the characteristic solar array profile until the battery charge voltage limit mode was reached. At this time, the charger input power decreased with the reduction of battery charge current demand. This device performed satisfactorily throughout the entire 271 day mission.

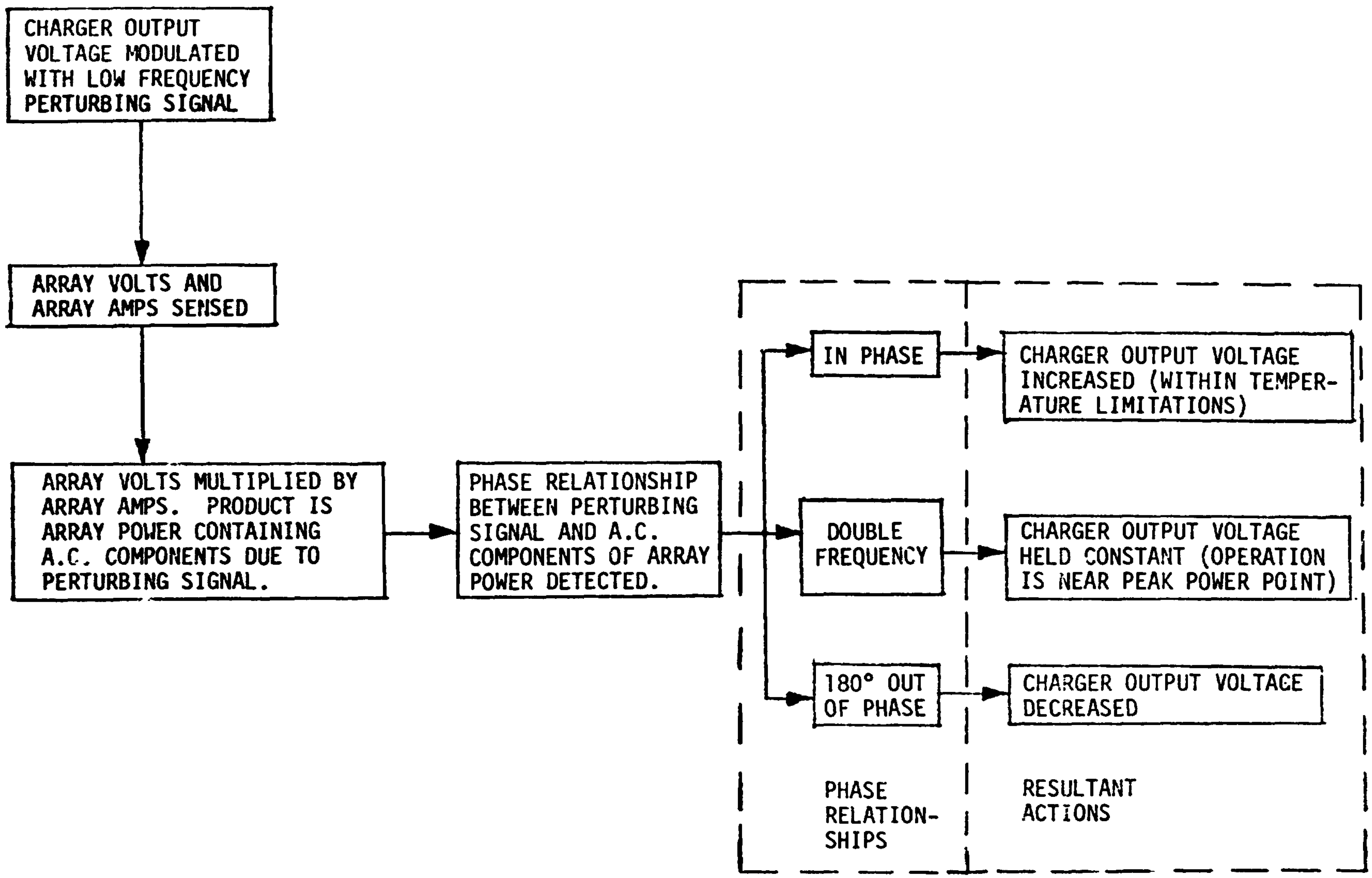


Figure 7.15 Peak Power Tracker Operational Diagram

2 Battery Voltage and Current Regulation. The battery charger was designed as shown in the simplified block diagram (Figure 7.16), so that the battery voltage would not exceed a limiting value imposed by battery temperature. Data showed that the battery charger limited the battery under charge to the correct value for the corresponding battery top-of-cell temperatures. Battery temperatures throughout the mission varied from 1 to 11 degrees Centigrade well within the predicted ranges.

Figure 7.17 illustrates battery voltage limit values versus battery temperature for the entire operating battery temperature range from 40 to 50°F experienced through the end of SL-3. Values are plotted for all eight PCGs in various orbits. A predicted performance is shown for comparison and a tolerance band for TM accuracy is also shown. The spread on the values for the various temperatures compared very favorably with the predicted performance values based on the battery charger acceptance test data.

When the controlling ampere-hour meter indicated that the battery had returned to 100 percent of charge, the battery current was regulated to 0.75 $\pm$ 0.5 ampere. The battery current curve, in Figure 7.15, shows the drop to the trickle charge level at the time that the controlling ampere-hour meter reached 100 percent charge. The current then remained stable at 0.9 ampere throughout the trickle charge region. This operation was typical for all eight power conditioners through the end of SL-3. In some instances during SL-3, the characteristics of the batteries were such that the battery voltage required to maintain the normal trickle charge current was higher than the voltage limit. In these instances, the battery voltage was limited to the voltage limit value, and as a result, the battery current was reduced below the normal trickle charge level. Performance remained normal throughout the remainder of the mission.

3 Ampere-Hour Meter Control. The ampere-hour meter tracked the battery discharge-charge profile in 1 percent (SOC) steps. The accuracy of readings was improved by including in the integration of battery charge current a temperature compensation factor, which corresponds to the battery temperature. Figure 7.18 is an operational diagram of the AHM. Figure 7.14 shows the typical relationship between the ampere-hour meter SOC indication and the battery current. The meter accurately registered battery discharge and charge. Upon reaching 100 percent, the battery charger control circuitry switched to trickle charge. The meter output remained at 100 percent until battery discharge began at the next sunset. Figure 7.19 compared the AHM SOC telemetry indications over one orbit to a calculated SOC over the same orbit. The calculated SOC value was based on battery current and temperature telemetry data and included the temperature compensation factor during charge. Considering the telemetry

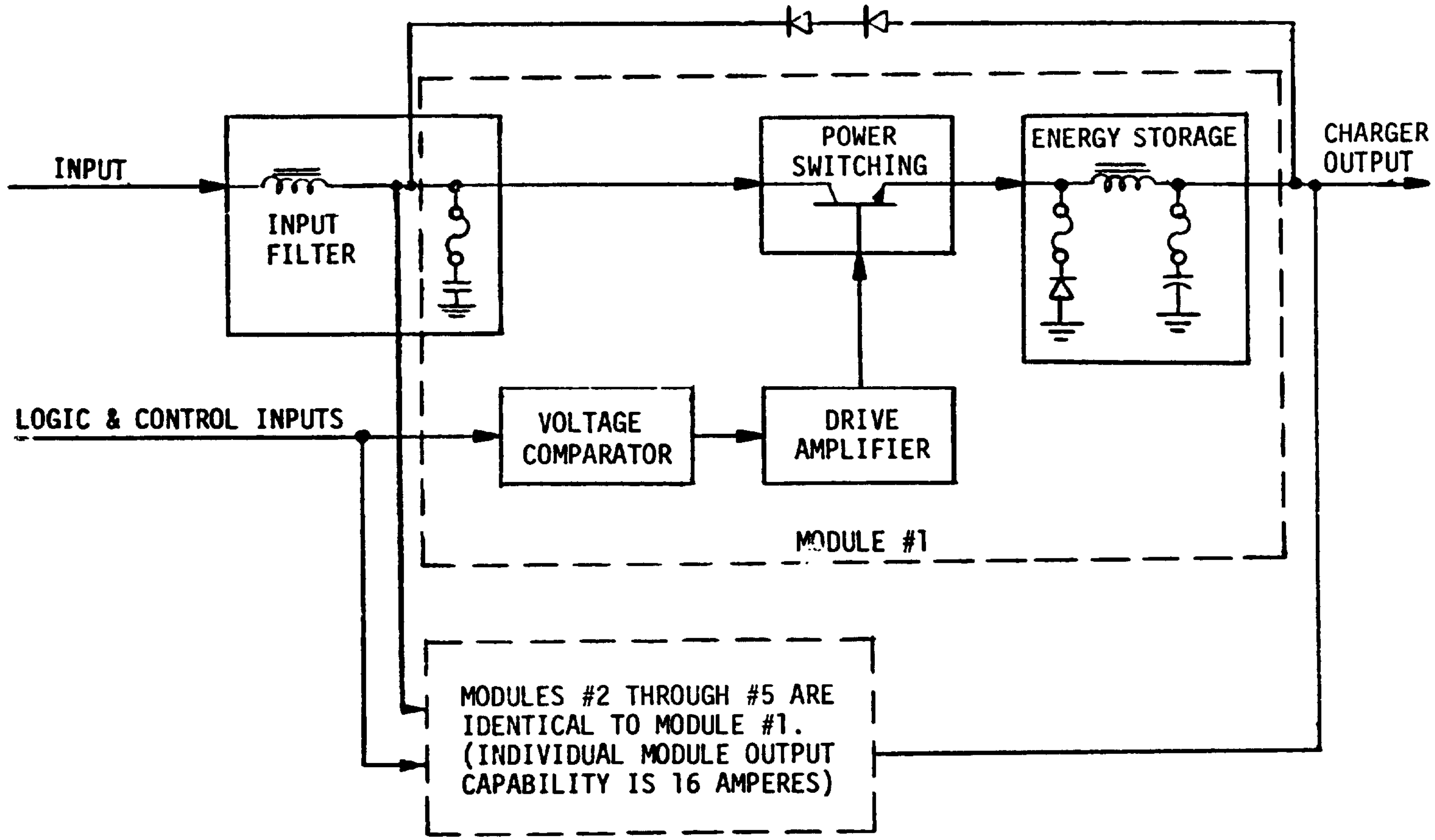


Figure 7.16 Switching Regulator Block Diagram

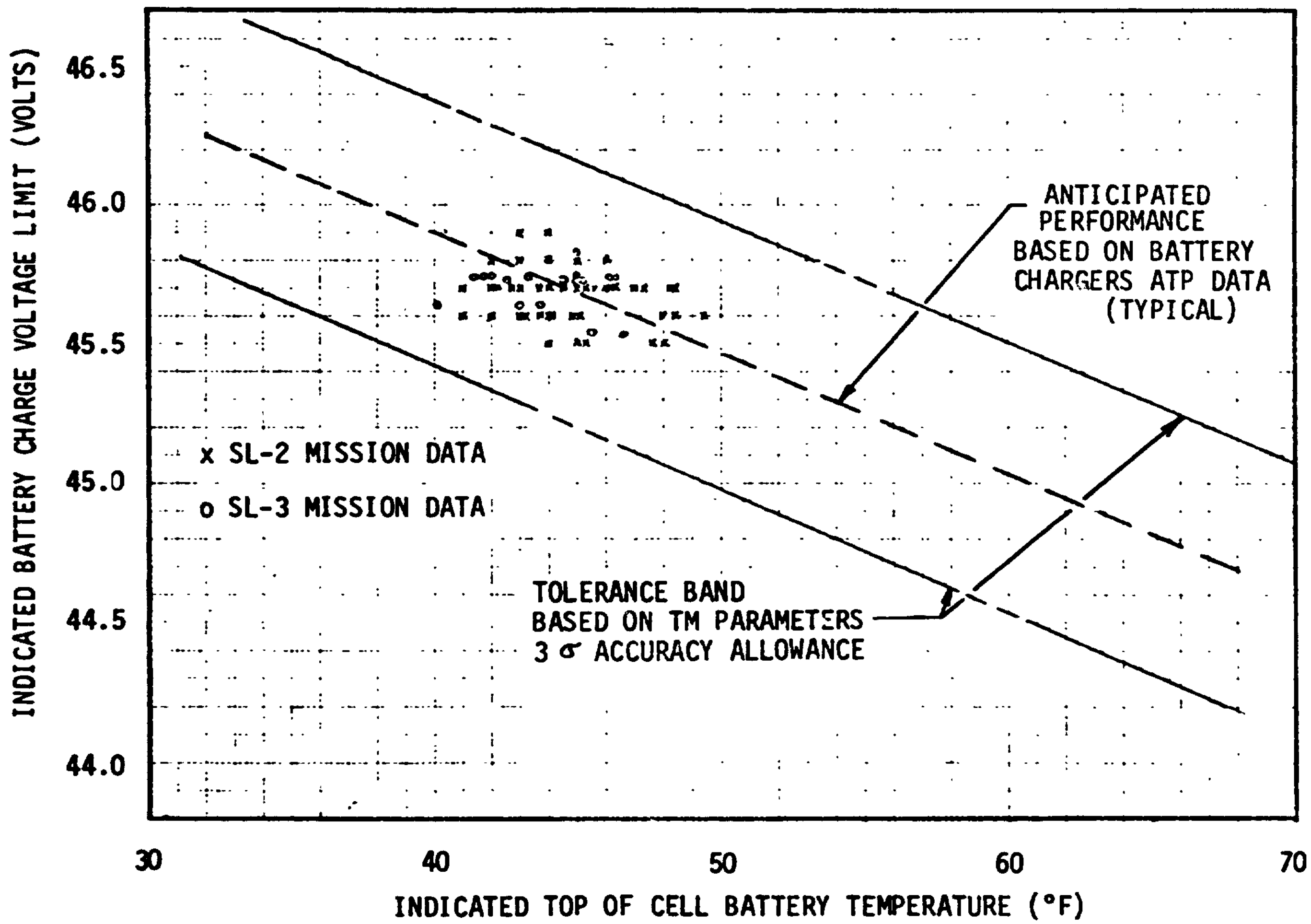


Figure 7.17 Limitations of AM Battery Charger Voltage (SL-1 thru 3 composite)

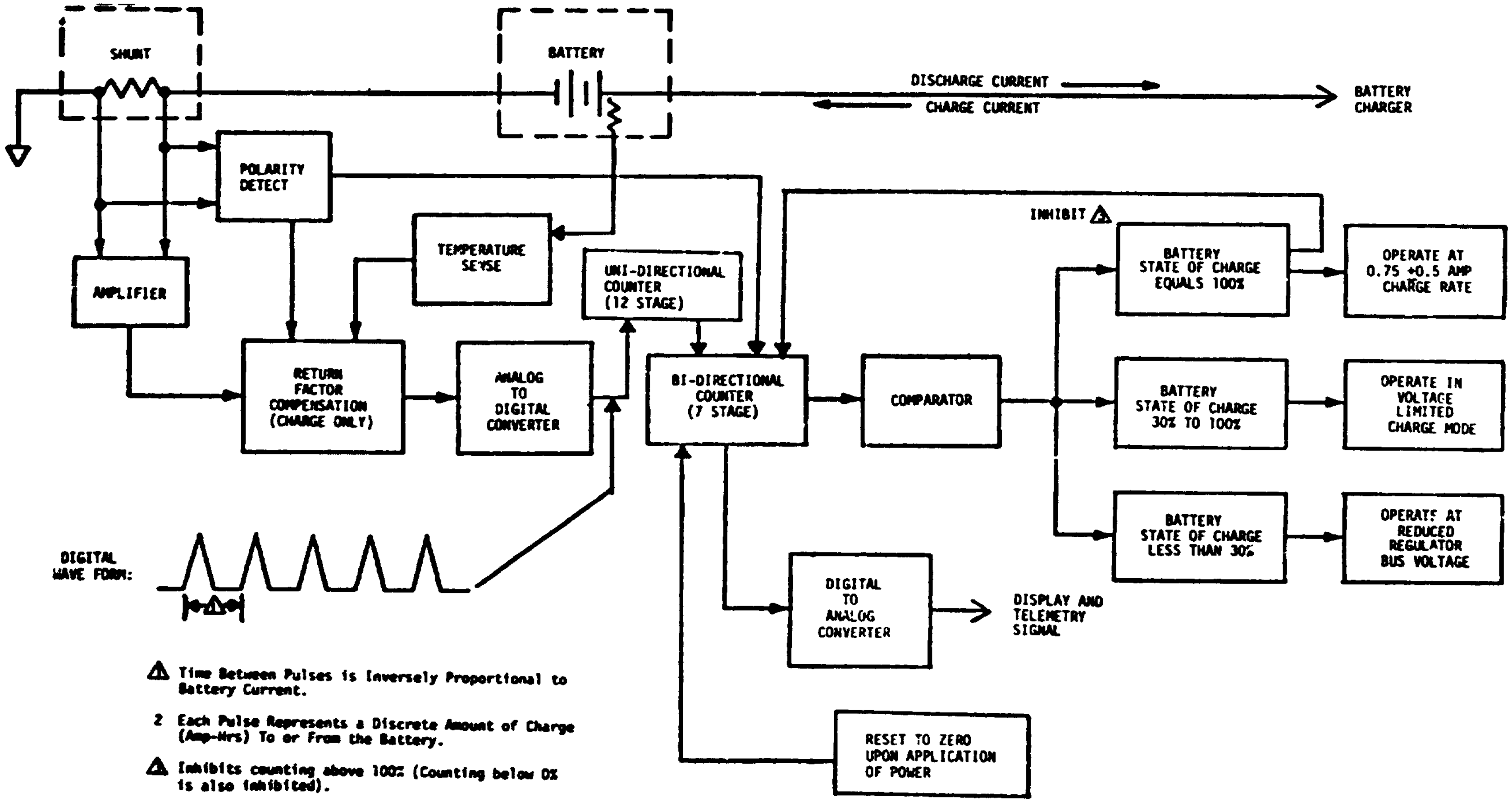


Figure 7.18 Ampere Hour Meter Operational Diagram

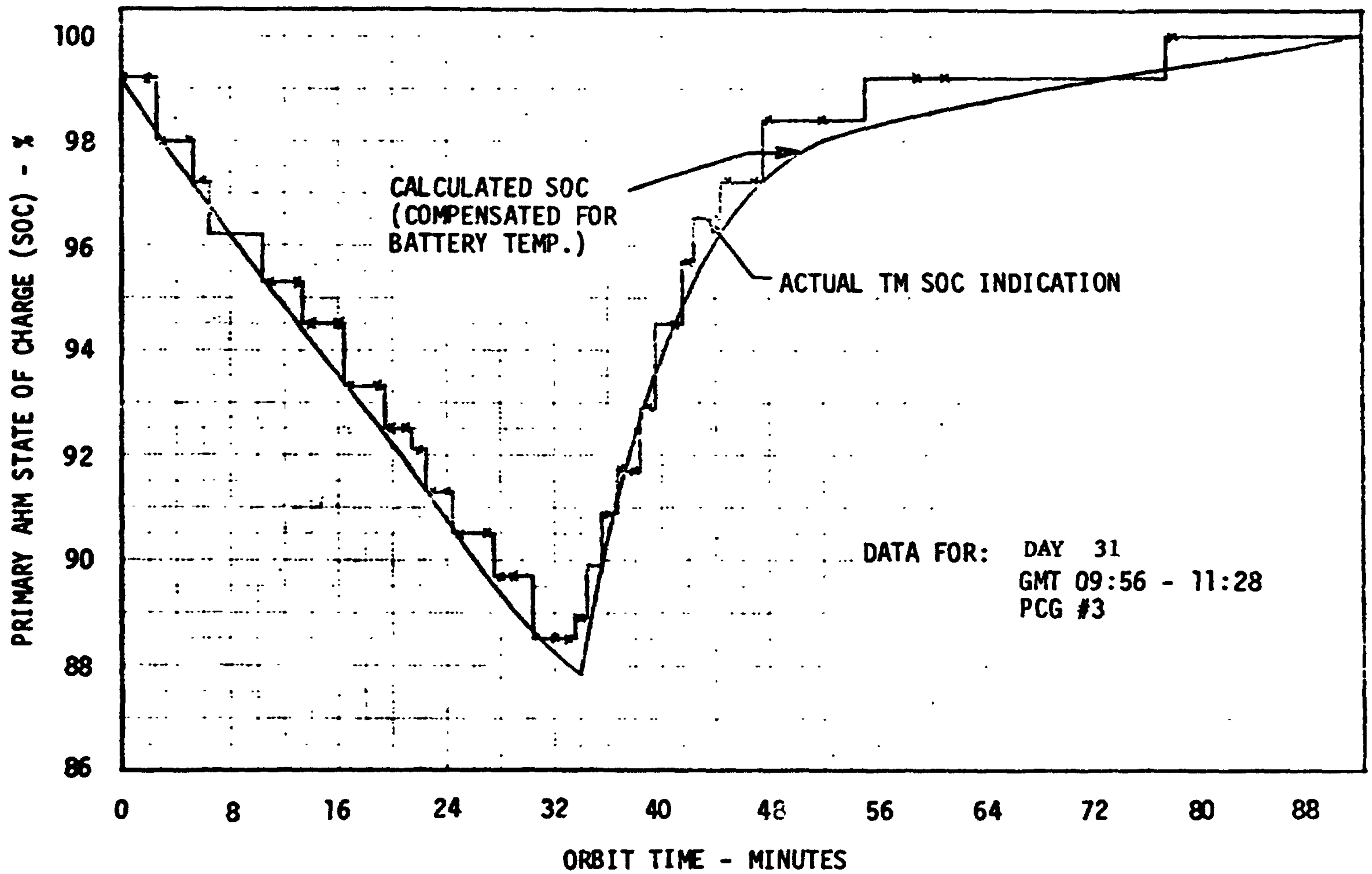


Figure 7.19 AHM SOC Integration Accruacy

accuracy limitation involved in the parameters used for the calculated curve and those on the direct SOC readings, the AHM SOC integration accuracy is seen to be very favorable.

The validity of this conclusion was borne out by the following performance observations. There were no indications of any hardware malfunctions or failures during these periods and there were no system performance effects as a result of the drift of the AHM indications. The AHM indications returned to correlation with other battery parameters after short periods of operation at reduced load levels.

Although the return factor was only compensated for battery temperature variations, the actual return factor varied a small amount with a number of other factors including battery depth-of-discharge (DOD), battery aging, etc. To allow for these other factors, the return factor was slightly conservative to assure that the battery was always fully charged when trickle charge was initiated. In addition to the design return factor being conservative, most of the flight AHMs exhibited a tolerance error in the device circuitry which was in the direction to increase the return factor.

At the beginning of a charge period, all available array power was delivered to the battery after the load was satisfied. The battery charger was peak power tracking at that time. As the battery accepted charge, the battery voltage slowly increased to the temperature compensated voltage limit value. The battery charger then maintained that voltage until the battery SOC, as indicated by the controlling AHM, reached 100 percent. As the battery approached a fully charged state, the battery current decayed. If the AHM reached 100 percent SOC prior to the end of the daylight period, the battery charger switched to trickle charge. If the AHM integrated SOC had not reached 100 percent prior to the end of the daylight period, the return factor had not been satisfied, and the battery charger maintained the voltage limit voltage at the battery terminals. This condition had been observed for several ampere-hour meters during the SL-3 mission and had also been observed in several ground system test programs. Although sufficient solar array power may have been available, the characteristics of the battery could have been such, that in the charging time available, the battery current at voltage limit was so low that the battery would not accept sufficient charge to satisfy the AHM return factor. The battery was, in fact, achieving a fully charged state. This had been demonstrated in ground test programs by capacity discharge testing of the battery after a number of cycles under these conditions.

Figure 7.20 shows a typical discharge-charge cycle during which the AHM SOC indication at sunset was less than for the previous sunset. During this cycle, the battery voltage reached voltage limit 31 minutes

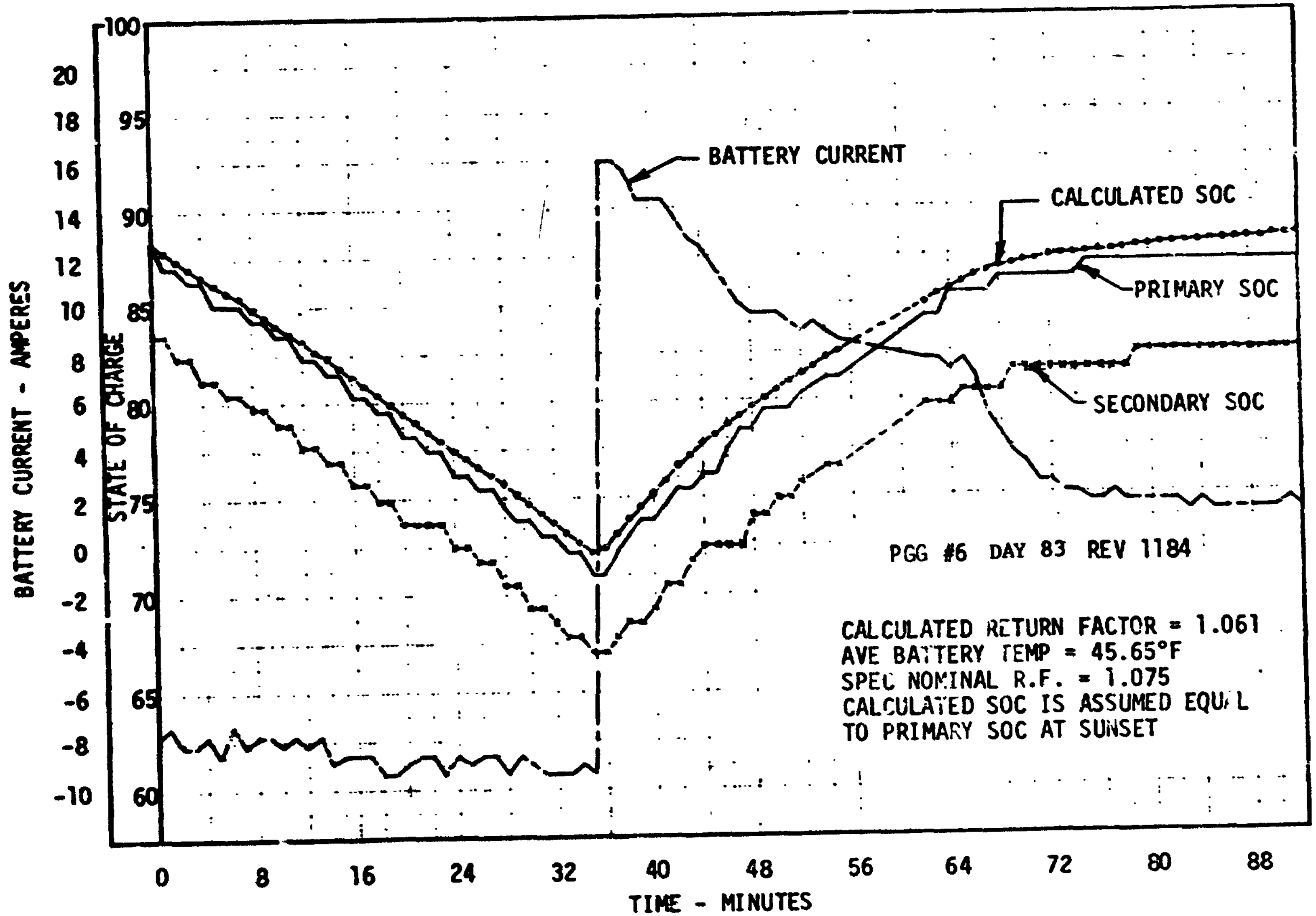


Figure 7.20 Battery SOC Integration (PCG 3, DAY 83 at 1184 revolutions)

after the beginning of the daylight cycle. The battery current decayed to a level of approximately one ampere and maintained this level for the remainder of the charge cycle. The calculated ratio of ampere hours returned to the battery to the ampere hours removed (actual return factor achieved) was 1.061. Since the AHM was designed for a return factor of 1.075 at the battery temperature observed, the AHM SOC indication could not recover to the previous sunset level. If the condition of the AHM return factor not being satisfied was maintained over a number of cycles, the AHM indication would decay downward. The AHM was an analog measurement device, and as such contained some error, both in battery current measurement and in the utilization of the battery temperature sensor to establish the return factor. Also, there was a small error which could occur in the transition from charge to discharge or from discharge to charge. If the AHM was not returning to 100 percent SOC, the effect of these errors was not erased each cycle and could accumulate. These cumulative errors could cause divergence between the primary and secondary AHMs and in some instances could aggravate a downward trend of the AHM SOC indication. Thus, if the AHM had not returned to 100 percent SOC over a large number of cycles, the AHM may not have had a close correlation to the actual battery SOC, and a divergence between the controlling and non-controlling AHM SOC indication could occur (Figure 7.21). Either or both of these conditions represented no compromise in system performance. Under these conditions, the battery charging current characteristic was the principal indication of the battery state of charge. Near trickle charge levels, for the final minutes of charge at the battery voltage limit, indicated that the battery was fully charged. Observation of battery voltage during discharge also provided an indication of proper battery state of discharge and had been observed to be normal in each instance observed on SL-3. The probability of not satisfying the AHM return factor increased sharply as the AM EPS load demand approached the AM EPS power capability. An analysis of data during SL-4 indicated that the downward trend of the AHM SOC indications occurred during periods in which the actual AM EPS load approached or exceeded the calculated AM EPS continuous power capability. The potentiometer adjustments, both reg bus and fine adjust affected the amount of power provided by each PCG and therefore affected which PCGs exhibited a downward drift of SOC indication at any particular time. The rate at which the AHM SOC indication recovered was directly related to the number of recharge ampere-hours in excess of those required to satisfy the return factor.

<u>4</u> Efficiency. The battery charger efficiency was considered to have been in the range from 90% to 94% for the operating conditions through the end of mission. This estimated level was necessary since reasonable efficiency calculations from flight data were not possible for the following reasons: 1) direct measurements of the battery charger output voltage and current were not available so a voltage regulator input power calculation was used which in itself was based on indirect measurements; 2) the accuracy limitations of several telemetry parameters led to a large uncertainty

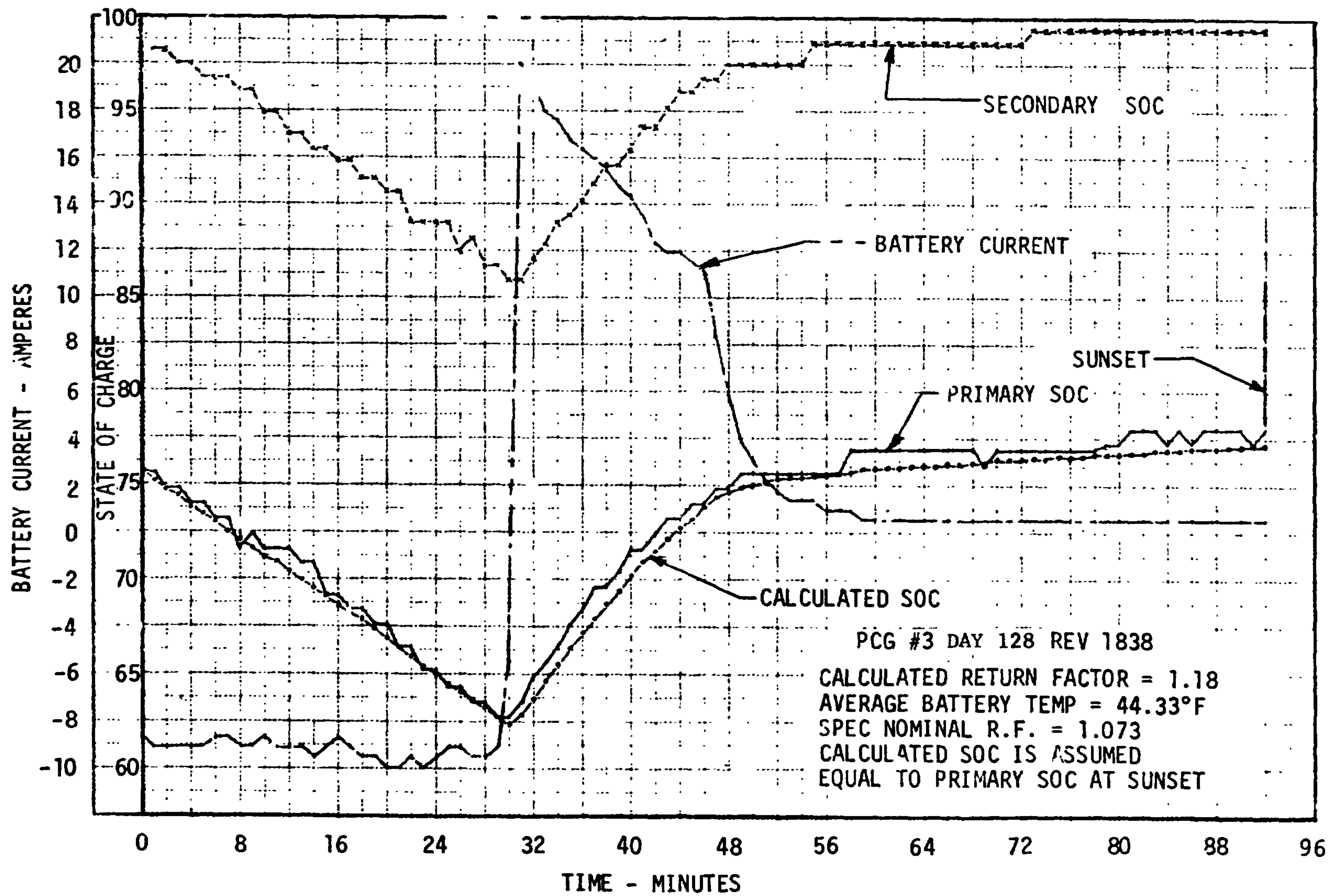


Figure 7.21 Battery SOC Integration (PCG 3, DAY 128 at 1838 revolutions)

in the calculated numbers, and 3) the low value of the losses, at the efficiencies being calculated, required very accurate calculations. The first two obviously made it impossible to satisfy the third. Overall operation in each PCG indicated continuous satisfactory battery charger efficiency through the end of mission.

(b) Batteries. Each of the eight batteries comprised 30, series-connected, nickel-cadmium, sealed cells. Each battery operated between 30 and 48 Vdc and had a 33 ampere-hour rating. Thermistors in each battery provided temperature sensing for telemetry, ampere-hour meter compensation, charge control, and protection against excessive temperatures. Active cold plates regulated overall case temperature.

The eight AM EPS batteries provided power during the launch phase. The batteries were then turned off at approximately 2 hours after liftoff when it was determined that workshop solar array power was not available. Batteries at this time ranged from 64 to 68 percent of full charge. This remaining capability was planned as a contingency power source for low power capability periods, such as during Earth observation experiment passes, and also to retain maximum flexibility in managing the batteries as the mission progressed and in the event of recovering all or part of the solar array.

On DAY 11, the batteries were turned on as it was determined that partial deployment of one wing permitted limited power production. They provided power only to the electrical power system control buses because all of the power conditioner output switches were in the Off position. All batteries were subsequently turned off again on DAY 12 after approximately 8 hours of operation. The percent of charge for batteries 1 through 4 at this time ranged from 48 to 53 percent. Batteries 5 through 8 were cycled on and off at various times for troubleshooting purposes and attempted charging. By DAY 22, batteries 5, 6, and 7 were recharged to 100 percent. Battery 8 could not be recharged to 100 percent. Battery 8 could not be recharged because its available solar array power was insufficient to operate the battery charger. Batteries 1 through 4 remained off until DAY 25 when they were again turned on in preparation for solar array wing 1 deployment.

That initial 24-day period, during most of which all eight batteries were turned off in a partially discharged state, constituted an abnormal storage period for the batteries. Recommended storage was either, in a discharged state (18 amperes discharge rate to 30 volts) for long periods, or in a fully charged state with weekly boost charge periods. Although no special operations were used to condition the batteries, they responded as originally expected when adequate solar array power became available to charge them.

Table 7.II shows the indicated percent of charge of the batteries just before and one orbit after solar array beam fairing deployment. The reading for battery 8 was abnormally low as a result of the ampere-hour meter being inadvertently reset to zero on DAY 14. Prior to that time it was reading 45 percent charged. The ampere-hour meters for battery 8 became synchronized with the actual battery percent of charge on DAY 29 and operated normally thereafter.

	State of Charge, Percent							
Time, GMT, Hr:Min	Batt 1	Batt 2	Batt 3	Batt 4	Batt 5	Batt 6	Batt 7	Batt 8
17:00	45.8	45.8	50.7	48.3	96.2	99.0	95.5	0
20:07	55.4	54.1	62.7	56.2	99.8	100.0	100.0	21.4

Table 7.II AM Batteries' State-of-Charge for DAY 25

All batteries demonstrated an ability to accept charge while exhibiting predicted voltages. This indicated that no adverse electrolyte distribution pattern had resulted from the "charged open circuit" abnormal storage.

Recovery of the state of charge indication for battery 8 as shown in Figure 7.22 provides qualitative information on charge retention during that period. The figure shows that once the measured 55% depletion was returned to the battery a different rate of recovery for the ampere-hour meter developed.

Battery cyclic performance from the time of solar array deployment until the first command and service module undocked was good. In the course of the first visit, 219 battery cycles were accumulated. Figure 7.14 shows a representative cycle profile of battery parameters. The charge voltage limitation mode resulted in some available power not being used, but the charge voltage on the battery was maintained at the proper level. This operational mode continued until cyclic battery inefficiency was satisfied by returning more ampere-hours than were discharged (overcharge), at which time the charge automatically reverted to a maintenance trickle charge. The trickle charge continued until the next discharge period.

The depth of discharge range most commonly experienced during the SL-2 mission was 12 to 14 percent. Depths up to 30 percent were experienced during high activity periods, or periods of other than solar inertial vehicle attitude. Continuous solar energy was

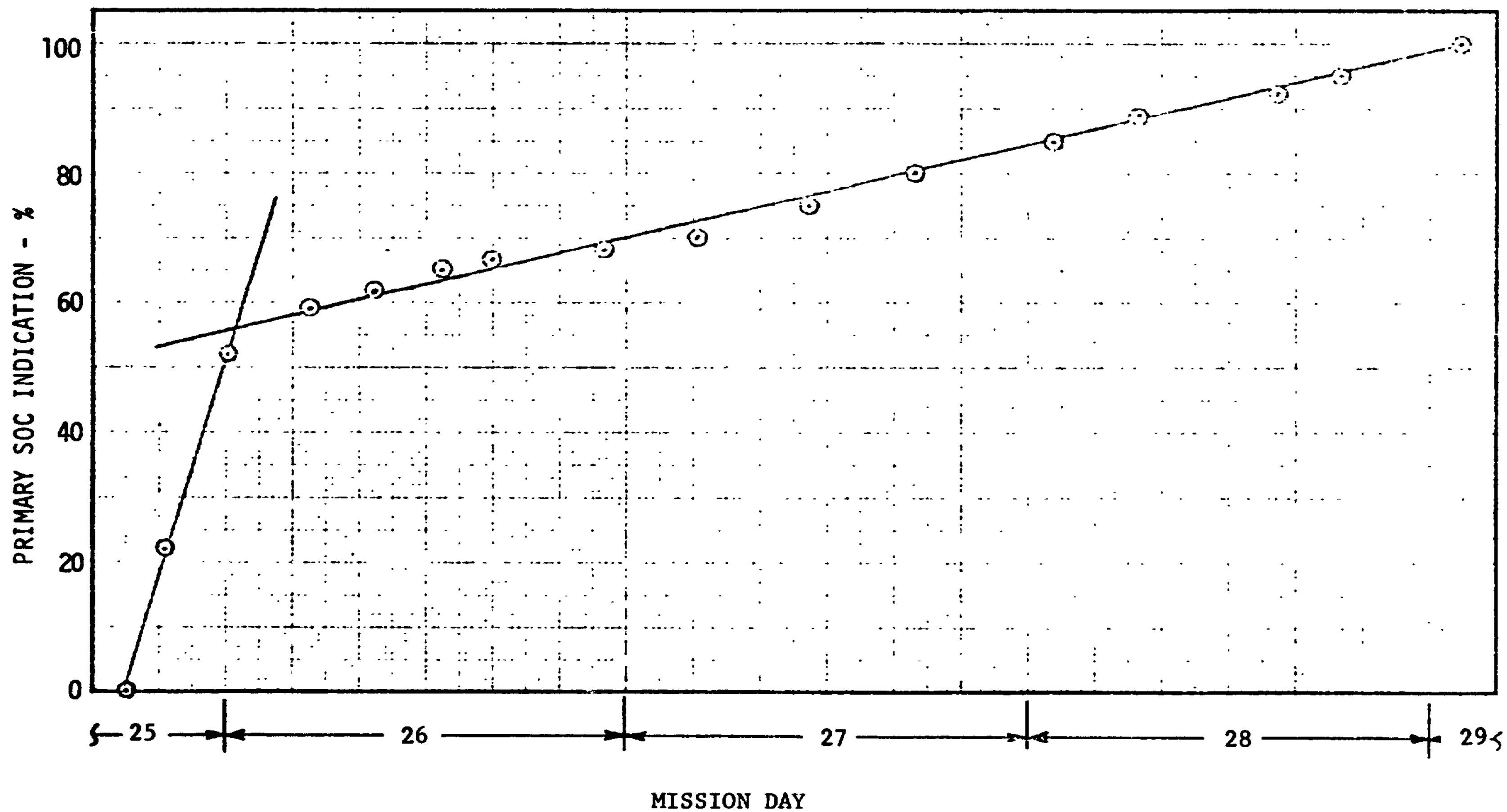


Figure 7.22 Battery SOC Recovery (PCG 8)

available to power the vehicle for the initial four days of the SL-2/SL-3 storage period because of the high beta angle conditions. The batteries, therefore, were subjected to continuous charging at the trickle charge rate for this entire four-day period. The battery temperatures remained stable and the charging potentials required to sustain the trickle charge rate for each battery converged toward a uniform level, as expected. The batteries resumed normal cyclic operation on DAY 44 and cycled at an average DOD of approximately 9 percent during the remainder of the storage period. Cycle accumulation at the time of SL-3 launch (DAY 76) reached 772 cycles. Composite battery discharge experience is presented in Figure 7.24. The data shown on these graphs covers the operating period from DAY 29 through DAY 39 and includes data points for all eight batteries. The telemetry data was scanned to obtain discharge current rates in the three different ranges: 6.0 to 7.9 amperes, 8.0 to 9.0 amperes, and 9.1 to 11.0 amperes. The curves indicate a linear and repeatable discharge voltage characteristic over the depths most consistently experienced during the mission. Where special mission activity resulted in greater depth of discharge than the normal, a plateau is seen. Similar results have been experienced during ground test programs.

Date dispersion resulted from instrumentation accuracy tolerance allowances. Individual voltage readings have an allowance of $\pm$ .25 volts and state of charge readings have an allowance of $\pm$ 2.5%.

It was anticipated that the coolant inlet temperatures to the batteries would exceed the vernatherm control valve setting of 39 $\pm$ 3°F and reach as high as 5_°F during periods of high crew activity (EVA) or non-solar inertial attitude. These conditions did not materialize, and the vernatherms maintained continuous control. Indicated top of cell battery temperatures consistently fell in the 40 to 50°F range. This was a favorable temperature range for battery cyclic life.

Batteries supplying the same AM regulated bus exhibited a uniformity of operation which made astronaut adjustment of the regulator fine trim pots unnecessary. Typical data which shows this uniformity is in Table 7.III. The discharge current shows that each battery increased slightly as its voltage decreased. This was caused by the constant regulator power demand on the battery. The curve for a 16 to 18 ampere discharge rate was obtained during performance of a battery capacity test on DAY 106. For this test, the regulator output voltage was adjusted to increase the load on battery 8, and the solar array input was disconnected from the power conditioners to maintain continuous battery discharge during the test.

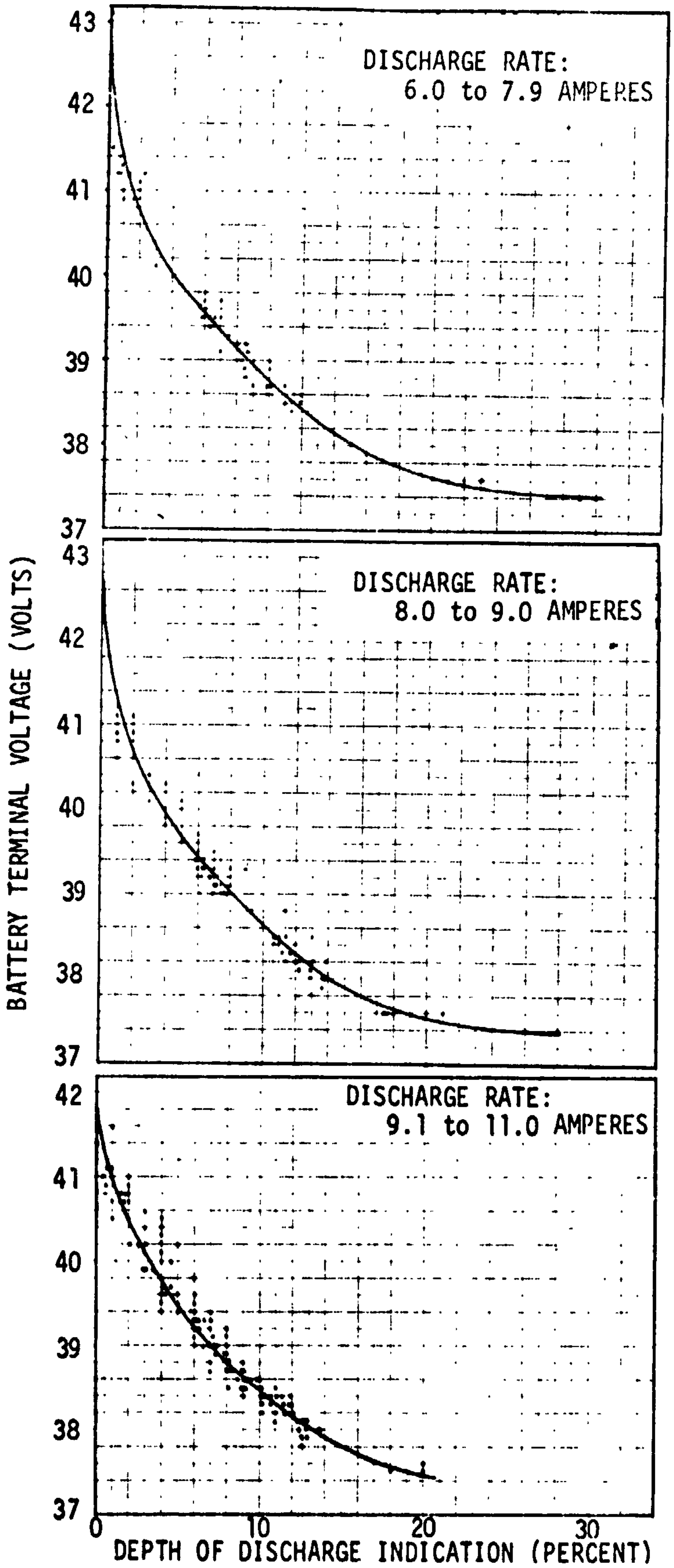


Figure 7.24 SL-2 Mission Composite AM Battery Discharge Characteristics

		Start of Discharge		End of Discharge		
Regulator Bus Number	Battery	Voltage, dc	Current, amperes	Voltage, dc	Current, amperes	Minimum State of Charge
1	1	41.78	8.74	38.32	9.44	88.5
1	2	41.79	8.66	38.23	9.37	88.1
1	3	41.99	8.59	38.23	9.38	88.5
1	4	42.08	8.68	38.23	9.39	89
2	5	41.57	8.97	38.02	10.15	87.5
2	6	41.68	9.39	38.03	10.18	86.3
2	7	41.88	9.30	37.83	10.97	87.4
2	8	41.78	9.53	37.83	11.27	86.3

Table 7.III Battery-Regulator Performance for Typical Night Orbit

In addition to the test on battery 6, a capacity test was performed on battery 8 on DAY 106 (Figures 7.25 and 7.26). Both batteries were purposely deep discharged to determine their available capacities. Capacity of the batteries had been determined in ground tests by measuring the ampere-hours extracted at an 18-ampere discharge rate to an end voltage of 30 volts. The inflight discharge procedure deviated from the ground practice in that the astronauts terminated the discharge when they detected a terminal voltage of 33 volts. The charger ampere-hour meter state of charge indication was used to measure the obtained capacities during these discharges. The results of these flight discharges are shown in Figures 7.25 and 7.26. The change in the general shape of the discharge characteristic since the acceptance testing of the units can be seen by examination of the figure. The characteristic exhibited at acceptance testing has in both cases changed to one in which initial voltage plateau developed at a lower level than a single plateau of the acceptance characteristic. The final few data points before the termination of the inflight discharges indicated the development of a second lower plateau, which is compatible with ground test experience. The increased prominence and duration of this second plateau and the recession of the initial plateau may have been partially a function of cycle accumulation.

Composite battery discharge experience for the SL-3 mission is presented in Figure 7.27. The SL-3 data shown on these graphs

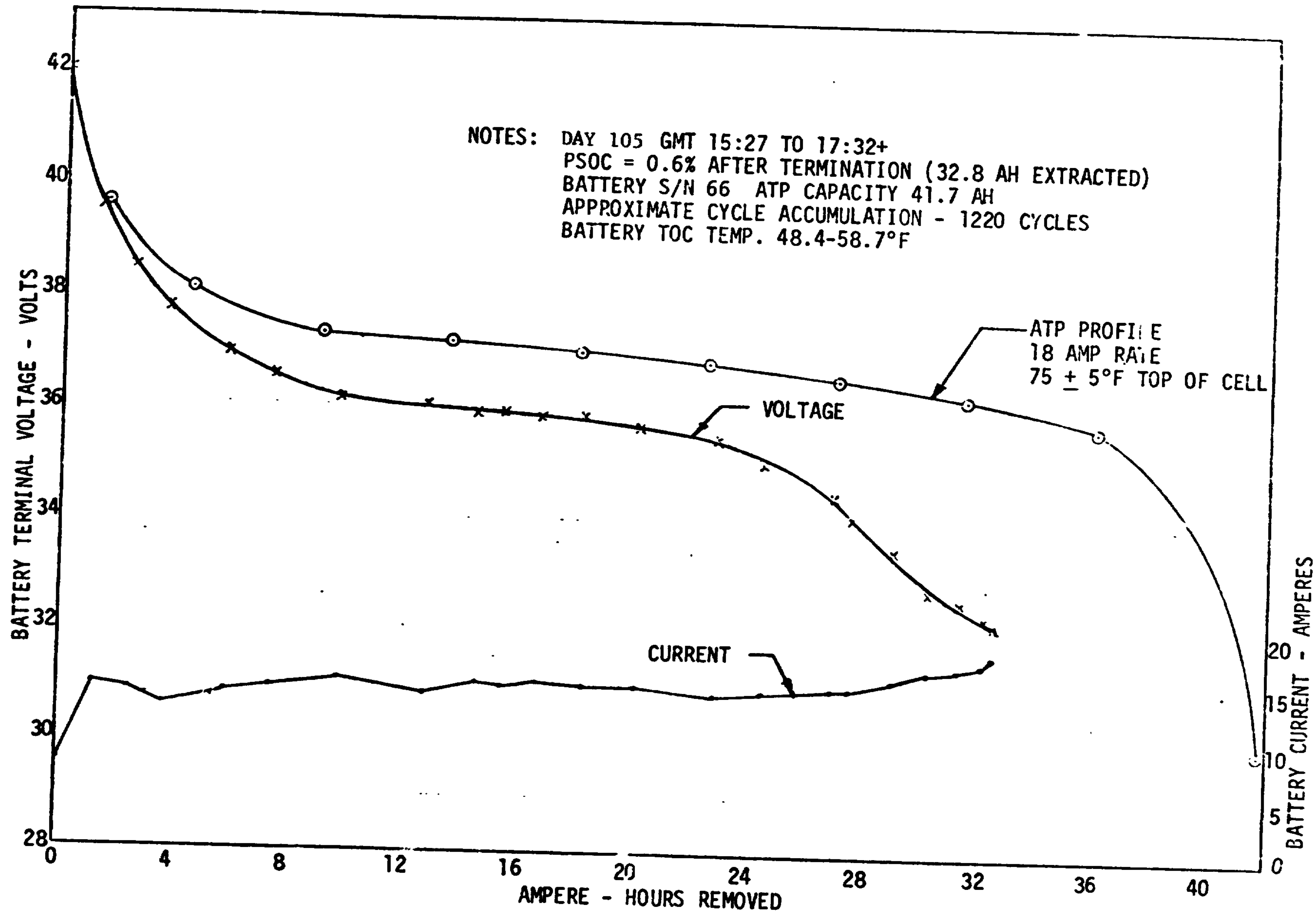


Figure 7.25 PCG 6 In-Flight Capacity Discharge

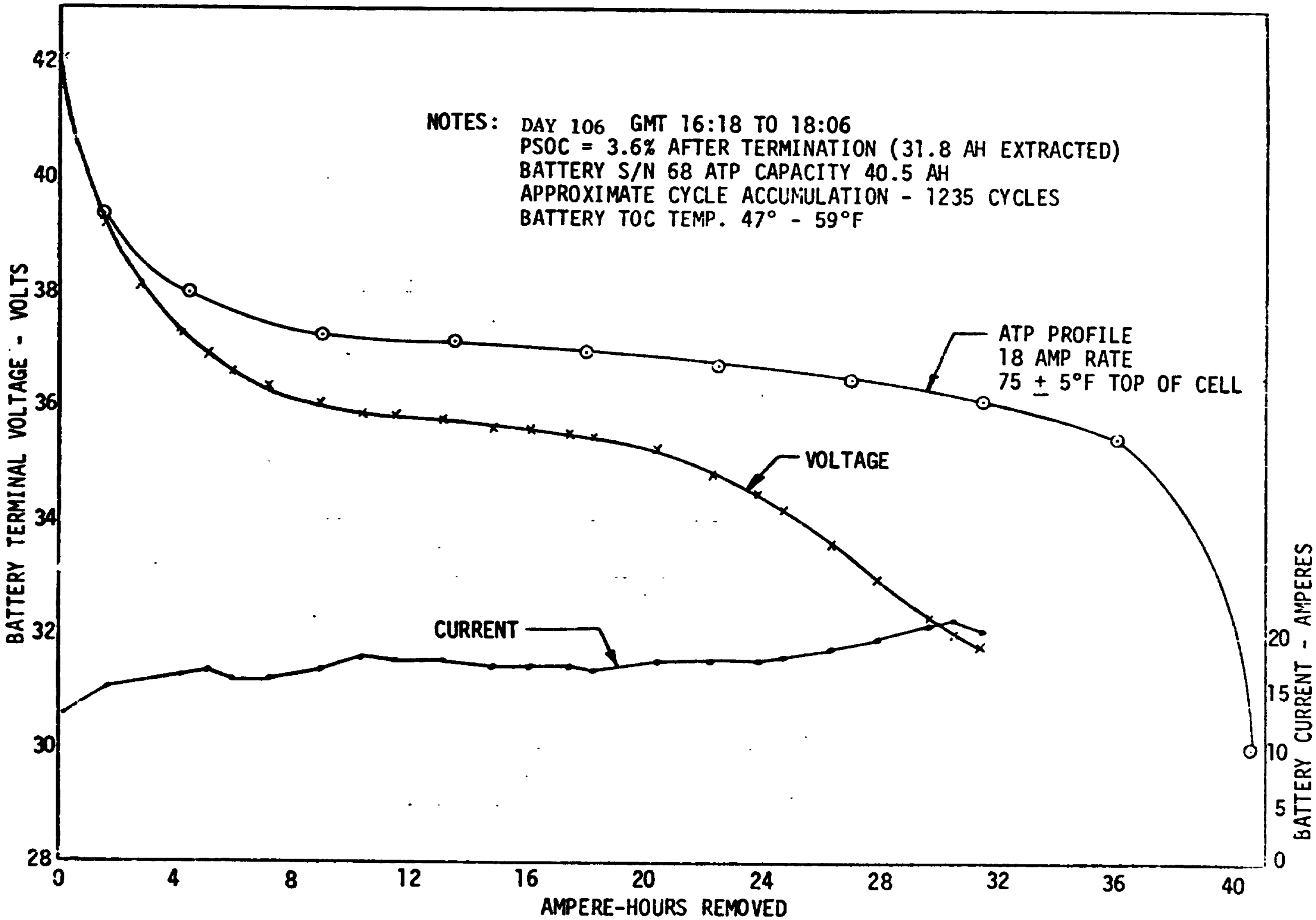


Figure 7.26 PCG 8 In-Flight Capacity Discharge

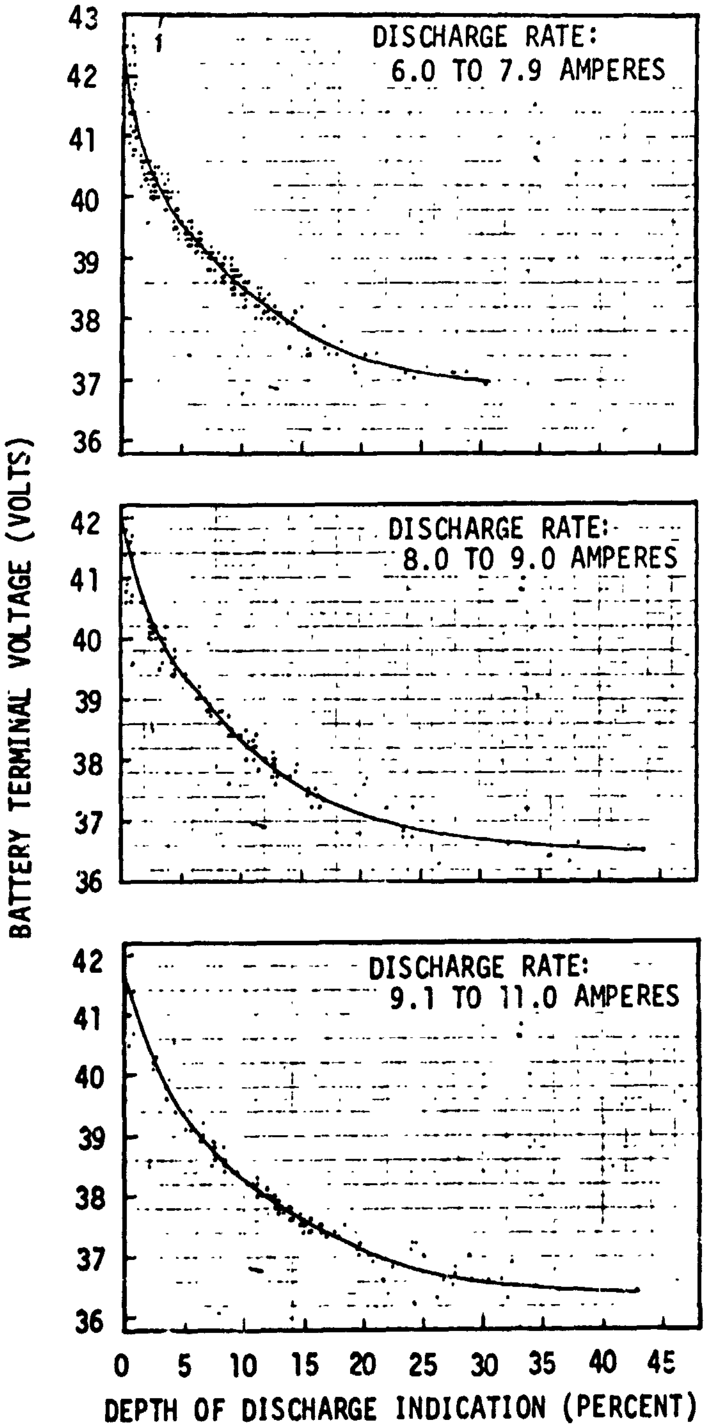


Figure 7.27 SL-3 Mission Composite AM Battery Discharge Characteristics

cover the operating period from DAYs 76 through 135. These data were selected and are presented in the same manner as the SL-2 composite data. A comparison of the SL-3 and SL-2 composite data indicates a detectable recession of the initial discharge characteristic plateau from what it was during SL-2 as previously stated.

A condition where some ampere-hour meters drifted from what was believed to be the actual state of charge of the batteries during the SL-3 mission was covered in the SL-3 battery charger discussion. Whereas battery terminal voltage was not an accurate means of determining individual battery state of charge, a comparison of several battery discharge terminal voltages at like delta-ampere-hour extraction points provided an indication of SOC status. This was done for several discharges occurring in the ampere-hour meter drift periods of SL-3 and showed comparable voltage levels for all the batteries. This voltage level consistency coupled with lack of a voltage degradation trend, indicated, in a qualitative way, that all the batteries were being fully charged irrespective of the ampere-hour meter indications.

The batteries had accumulated 1683 flight cycles at the time the second crew departed on DAY 135. The depth of discharge range most commonly experienced during the second manned period was 13 to 16 percent. Forty-one Earth observation passes were performed during this mission. Battery depths of discharge were generally greater during these passes than during normal solar inertial operation. The maximum depth of discharge experienced occurred during the final pass, DAY 131, when depths ranged from 36 to 42.7 percent.

Each AM battery was actively cooled. Parallel coolant flow at controlled temperatures (40 +2 -4°F) was provided to coldplates for batteries 3, 4, 7, and 8. The coolant from these coldplates was available for batteries 1, 2, 5, and 6, respectively, in such a manner that for each pair, the heat picked up from the first battery increased the coolant inlet temperature at the second battery.

On DAY 104, a coolant loop system operational change decreased the coolant mass flow by approximately 50 percent. The effects were detectable by an approximately 2°F increase in the operating temperatures of batteries 1, 2, 5, and 6. Changes in the temperatures of batteries 3, 4, 7, and 8 were too small to be detected in the telemetry scatter. Other than this detected increase, the indicated top of cell (TOC) battery temperatures were comparable to those experienced during the first manned period.

Contingency planning called for discontinuing PCG operation during SL-3/SL-4 storage in the event of coolant loop depletion. However, the batteries cycled throughout the entire storage period, as execution of the contingency plan was unnecessary. By the time of the launch of SL-4, the batteries had accumulated 2486 cycles. The cycle depths which averaged approximately 7% during this period were less than those of the first storage period because of the EPS configuration established per the modified SL-3 AM EPS shutdown procedure.

AM battery discharge/charge cycle accumulation, at the time the SL-4 crew departed on DAY 271 was 3790 cycles. The range of discharge depths experienced during the solar oriented periods was 12 to 19%. Discharge depths near 50% were common for the off-sun experiment orientations with the maximum depth reaching 57%. Composite battery discharge experience for the SL-4 mission is presented in Figure 7.28.

One hundred and ten non-solar oriented attitudes were established in the course of the mission for Earth Resource and Comet Kohoutek observations. Failure of a Control Moment Gyro, on DAY 194, resulted in more off-sun attitude time than normally would have been required to accomplish the desired observations. AM battery performance was uniform and reliable during the mission. Their ability to sustain the heavy depths of discharge dependably contributed to the high success level of the mission.

Capacity discharges were performed on PCG 6 battery at the beginning, in the middle, and at the end of the SL-4 manned phase. The first two discharges were performed according to the procedure used in the SL-3 mission while the third, SL-4 discharge, was continued until the battery terminal voltage reached 30.0 volts. As mentioned previously, the 30.0 volt termination was consistant with ground test practice. The results of these tests are shown in Figure 7.29. A consistent pattern of battery output voltage regulation degradation with increasing cycle accumulation can be seen when SL-3 capacity discharge information for PCG 6 is added to the informatiin contained in Figure 7.29. This progressive pattern of nickel-cadmium "memory" development was apparently minimally affected by incomplete capacity discharges.

A special EPS configuration was established as part of the SL-4 crew closeout of the Skylab. This was done in anticipation of capacity testing of all AM batteries after the crew departure. The devised system configuration allowed ground selection of any one of the eight AM batteries for discharge, established discharge rates near the ground test level of C/2, permitted continuous discharge of the selected battery to a 30.0 volt completion, and provided a self limitation of battery discharge as the battery terminal voltage approached 29.0 volts. The last feature was desirable as ground station coverage could not be assured at every critical discharge time. The flexibility of the AM EPS control capability proved invaluable in accomplishing the test objectives.

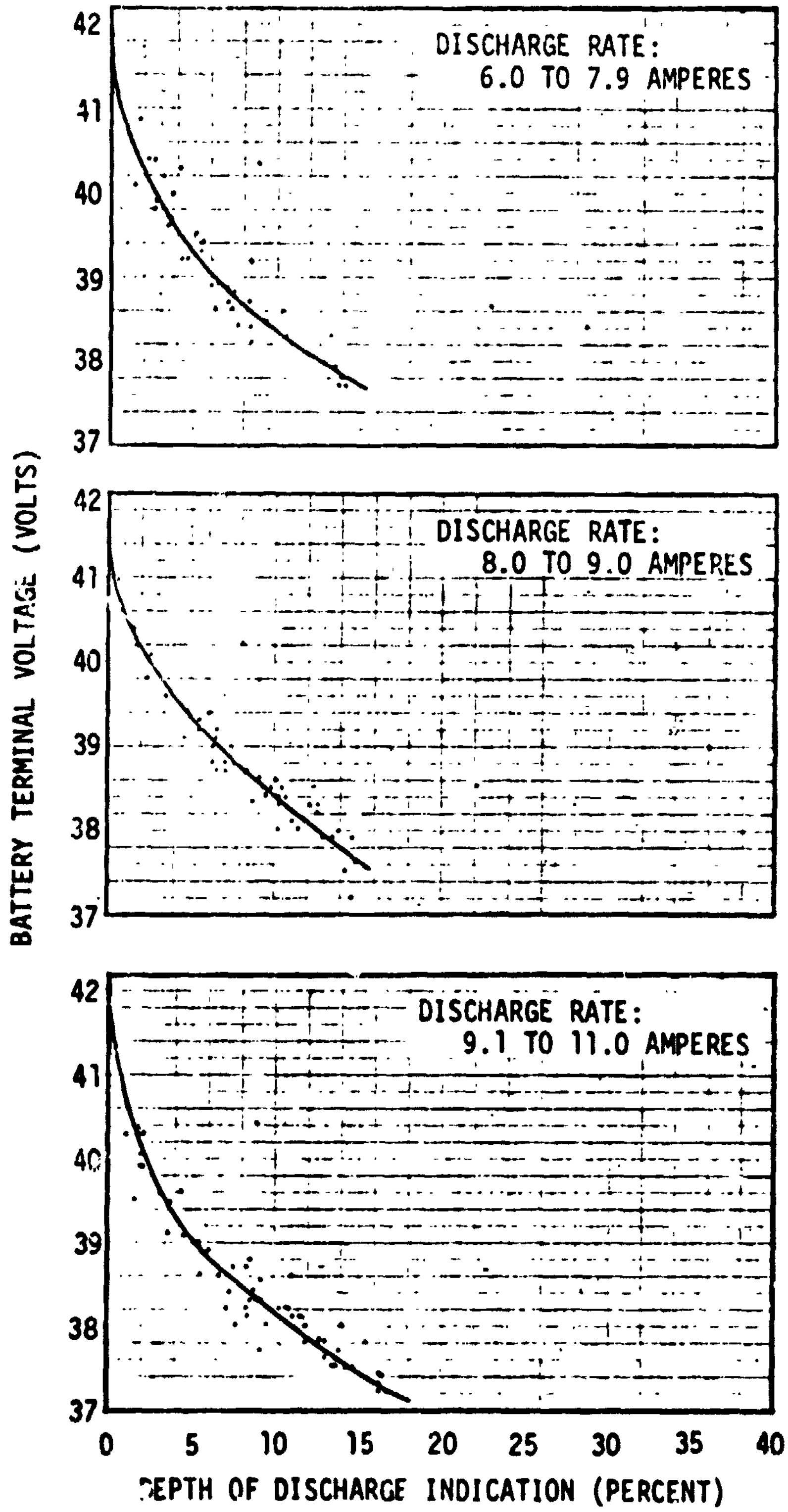


Figure 7.28 SL-4 Mission Composite AM Battery Discharge Characteristics

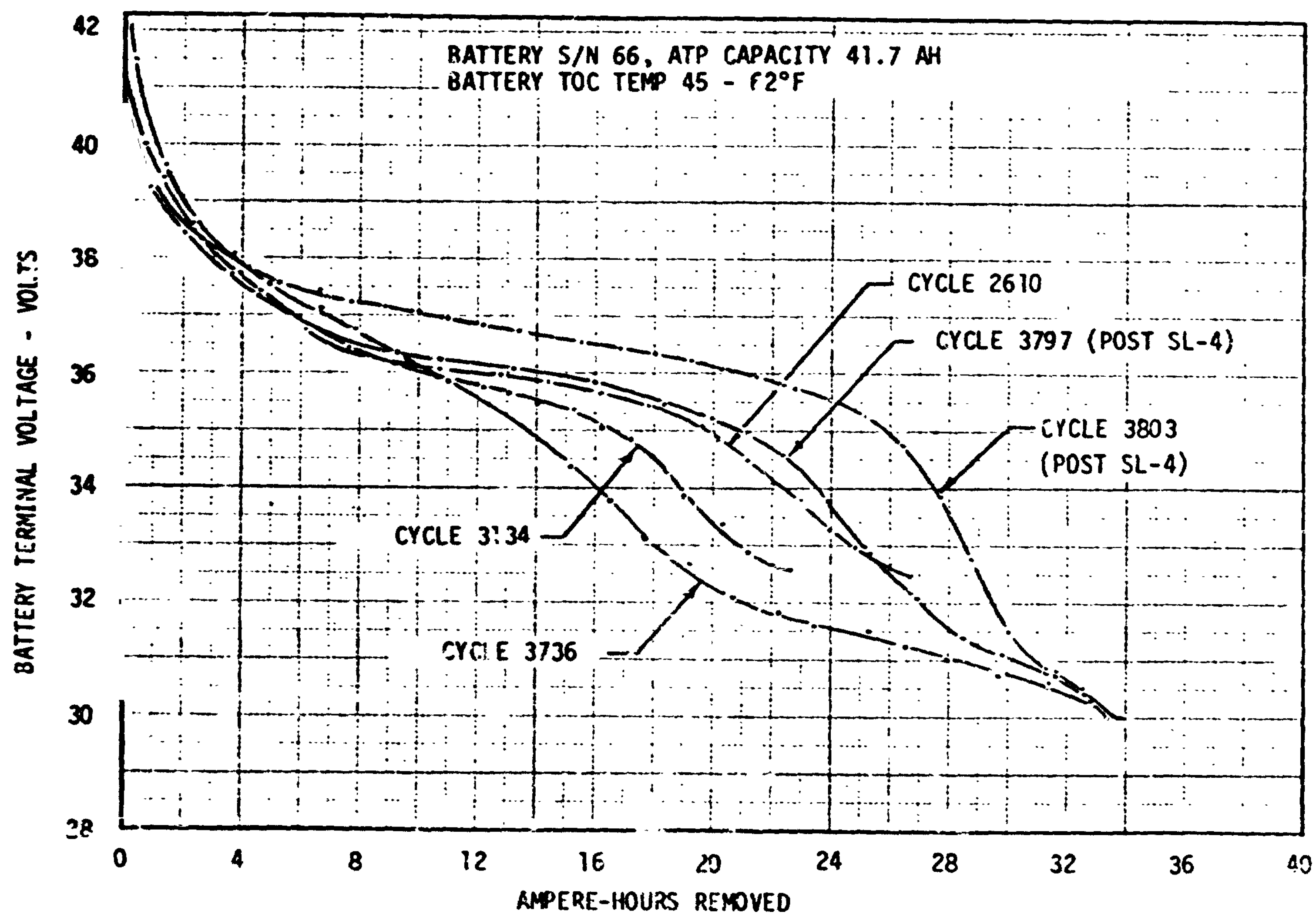


Figure 7.29 PCG 6 In-flight Capacity Discharges

All eight AM batteries were discharged to 30.0 volts during the post SL-4 test period. In addition, PCG 6 and 8 batteries received a second full capacity discharge during this test period.

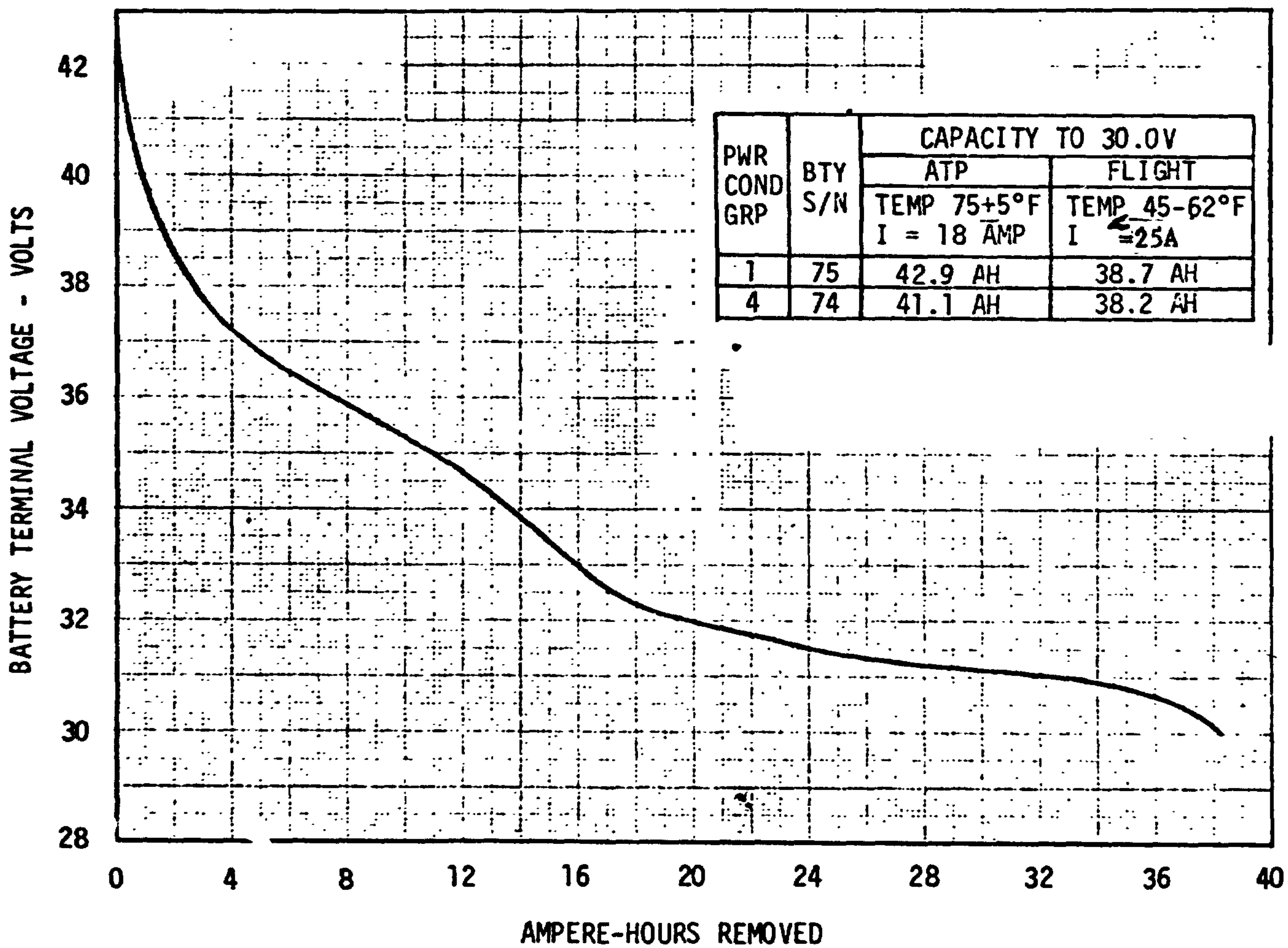
Three distinct discharge profiles were found to exist. Figure 7.30 depicts the discharge characteristic of PCG 1 and 4 batteries, while Figure 7.31 shows the characteristic of the remainder with the exception of PCG 6.

PCG 6 battery, which was discharged to 30.0 volts shortly before the crew departed, exhibited discharge characteristics as shown in Figure 7.29. When comparing these figures and previous ground test experience on units with similar history, a marked consistency was noted except for the duration of the second voltage plateau which began at about 16 amp-hrs. One possible contributing factor to this difference was the length of time the various batteries were in the vehicle before launch. PCG 1 and 4 batteries were in the vehicle 22 days prior to launch, while the rest were installed sixty-eight days before launch. The second voltage plateau for PCG 1 and 4 batteries was longer, and resulted in greater amp-hour capacity.

Comparing profiles of Figure 7.39 and the 3736 cycle profile of Figures 7.30 or 7.31 indicates that PCG 6 battery had a slightly better performance characteristic than other batteries of similar history. As was mentioned earlier, incomplete capacity discharges did not affect the onset of "memory" appreciably. The difference noted here are small and are felt to be the result of periodic partial discharges of PCG 6 battery during the Skylab mission.

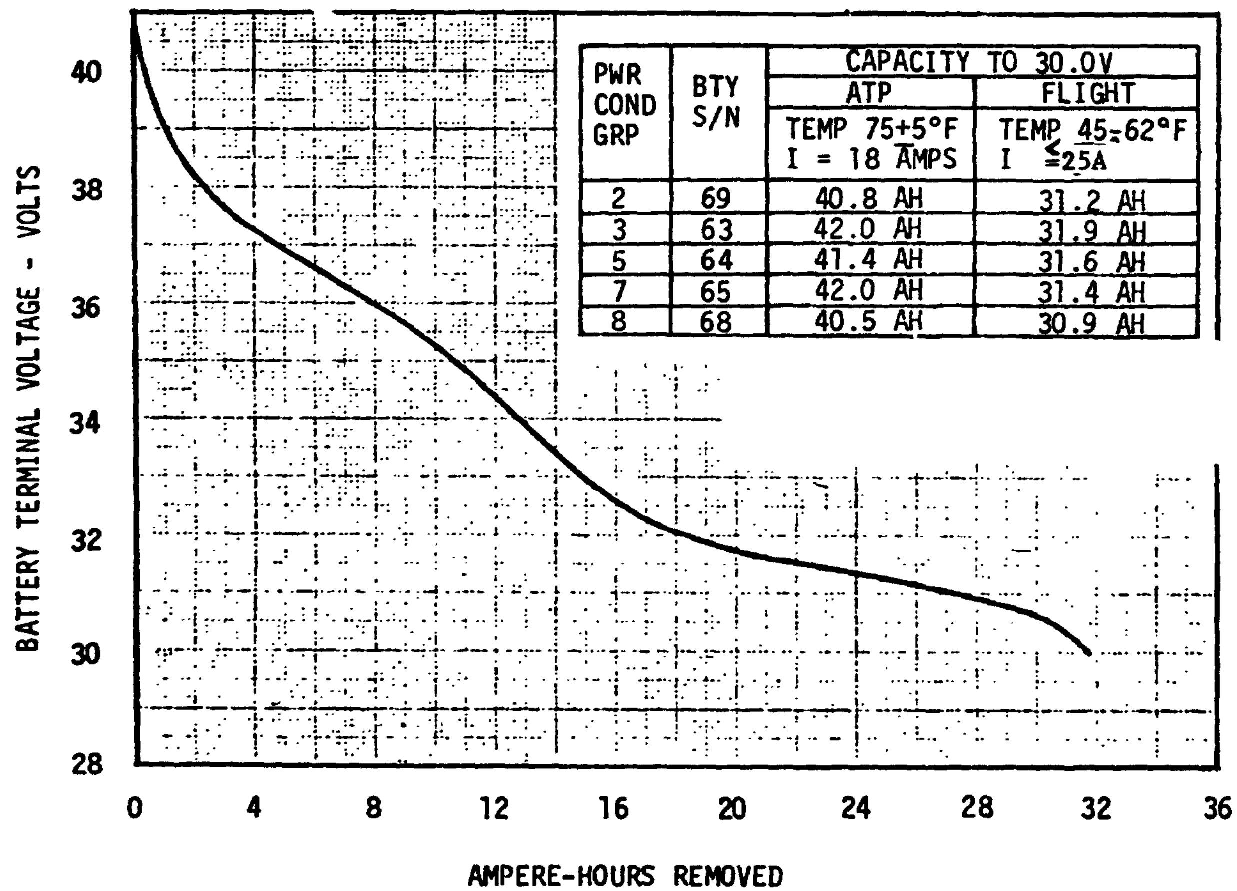
The more pronounced effect of full capacity discharges on the subsequent discharge profiles can be seen in Figure 7.29 by comparing the 3736 cycle to the 3797 cycle and finally to the 3803 cycle. This same phenomenon was present in PCG 8 battery's end of mission capacity data and in AM ground test experience with life cycle batteries.

(c) Bus Voltage Regulators. Eight bus voltage regulators supplied voltage to two main buses (Figure 7.32). The charger normally supplied power to the regulator; however, a bypass switch allowed the solar array power to feed directly to the regulator in the case of a charger malfunction. A potentiometer simultaneously adjusted the output of all regulators which were tied to the same bus. This bus voltage adjustment was made to regulate load sharing between the AM/OWS power system and the other Skylab power sources. Fine adjustment potentiometers regulated load sharing by the individual regulators.



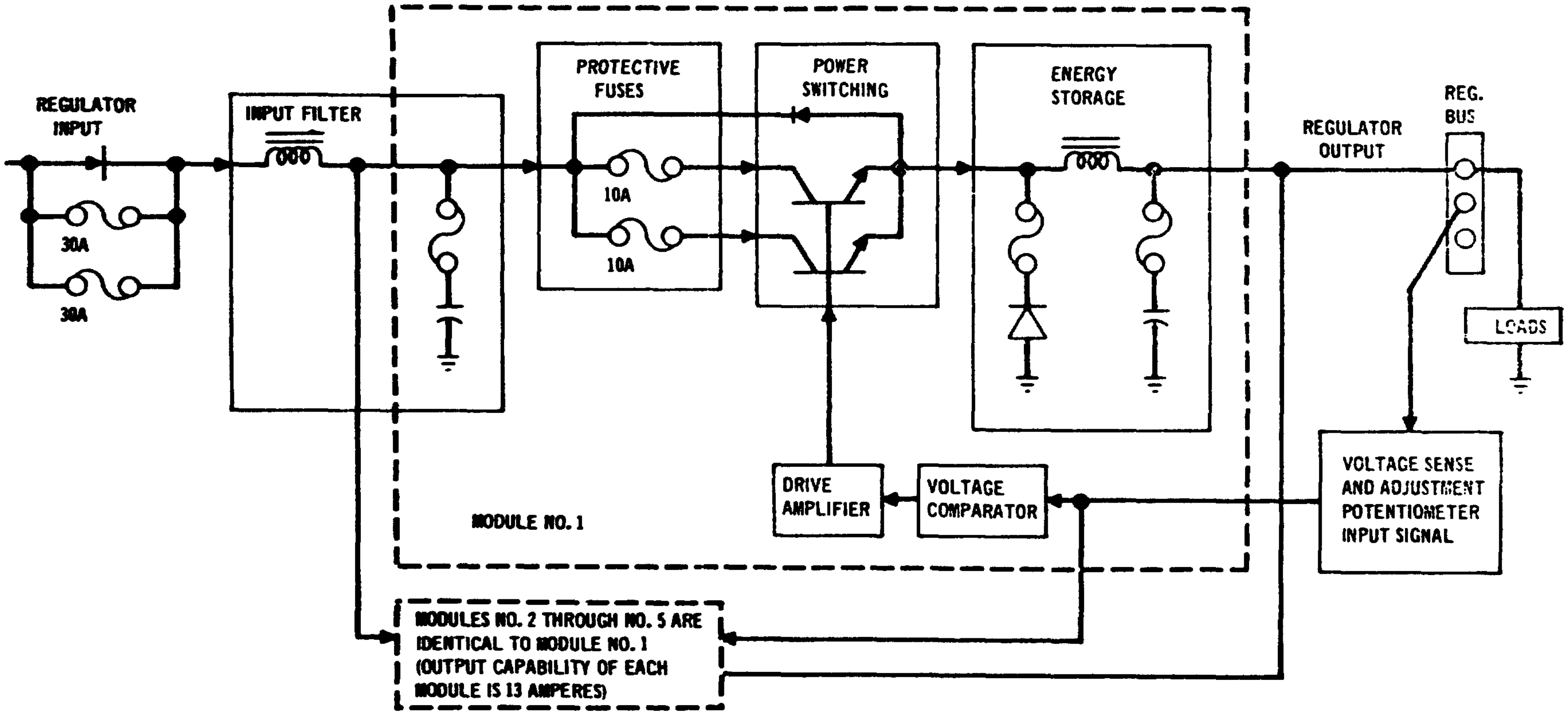
PWR COND GRP	BTY S/N	CAPACITY TO 30.0V	
		ATP	FLIGHT
		TEMP 75+5°F I = 18 AMP	TEMP 45-62°F I = 25A
1	75	42.9 AH	38.7 AH
4	74	41.1 AH	38.2 AH

Figure 7.30 Typical 3800 Cycle Discharge Profiles (PCG 1 and 4)



PWR COND GRP	BTY S/N	CAPACITY TO 30.0V ATP TEMP 75+5°F I = 18 AMPS	CAPACITY TO 30.0V FLIGHT TEMP 45-62°F I ≤25A
2	69	40.8 AH	31.2 AH
3	63	42.0 AH	31.9 AH
5	64	41.4 AH	31.6 AH
7	65	42.0 AH	31.4 AH
8	68	40.5 AH	30.9 AH

Figure 7.31 Typical 3800 Cycle Discharge Profiles (PCGs 2,3,5,7,8)



NOTE: MODULE OUTPUT VOLTAGES ARE SET AT DIFFERENT LEVELS SO THAT MODULES ARE AUTOMATICALLY ADDED TO SATISFY INCREASING LOAD REQUIREMENTS.

Figure 7.32 Voltage Regulator Block Diagram

Before SL-1 launch the individual regulator potentiometers were set to a value that permitted all 8 batteries to discharge at a uniform rate. This was done to compensate for the variations in battery cells, differences in the individual circuit and component resistances, and differences in regulator efficiencies. Analysis of flight data for the complete mission indicated normal operation of all 8 regulators. Specific fluctuations within the regulators are discussed in the following paragraphs.

1 Bus Voltage Regulation. Throughout the mission the voltage regulator conditioned power from both the battery and the battery charger. As a result, its input voltage varied in the range from 38 to 46 volts. As shown in Figure 7.33 the regulated Reg bus voltage was not affected by the relatively large variance in input voltage. The small fluctuations in Reg bus voltage seen were attributable to bus load variations and/or telemetry data conversion accuracy limitations. This condition was typical for the entire Skylab mission.

2 V-I Output Characteristic. With four voltage regulators operating on each Reg bus, the bus voltage decreased from open circuit voltage (OCV) by 0.01 volt per ampere of load. Figure 7.34 shows the relationship of telemetry data points to predicted V-I curves. The curves are based on a 0.01 volt per ampere droop and Reg Bus 2 OCV settings of 29.22 and 29.45 volts. These values closely approximate the desired settings for DAY 31 and 37, respectively. Considering the accuracy limitations on the telemetry data, the data points compare favorably with the predicted curves and the comparison was typical for both Reg buses. The Reg Bus potentiometers were adjusted several times during SL-1/SL-2 for the purpose of regulating AM load level or the AM/ATM load sharing. The potentiometer adjustments were made over nearly the entire adjustment range from nearly full CCW to a 29.5 OCV setting. For the purpose of power management, several adjustments of the Reg Adjust potentiometers were made during SL-3. However, at no time were adjustments imposed for either voltage regulation drift or instability purposes. The expected bus voltage "droop" of 0.01 volts per ampere was observed for each open circuit voltage setting. An OCV of 29.45 volts for Reg Bus 2 was maintained throughout the SL-2 to SL-3 storage period and the first ten days of SL-3. Thus the data for DAY 78 follows the same V-I curve as the SL-2 data of DAY 37. The data of DAY 134 follows the V-I curve corresponding to an OCV of 29.02 which was maintained for Reg Bus 2 at that time. The SEPSA computer program which simulated the normal AM/ATM distribution system was used to calculate the amount of adjustment to be made. Each adjustment in Reg bus voltages and AM/ATM load sharing compared favorably with predictions.

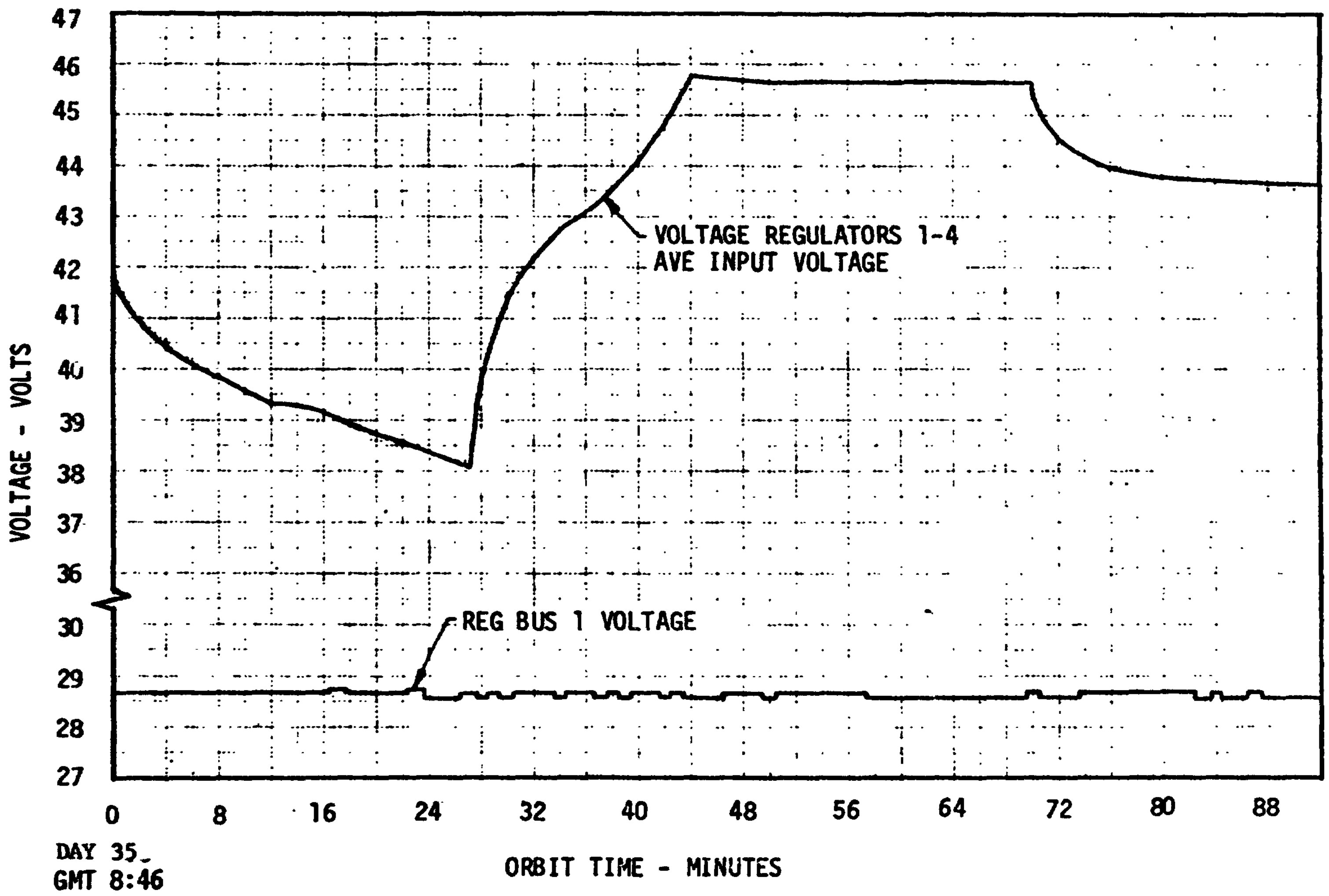


Figure 7.33 Typical Voltage Regulator Voltages (Input and Output)

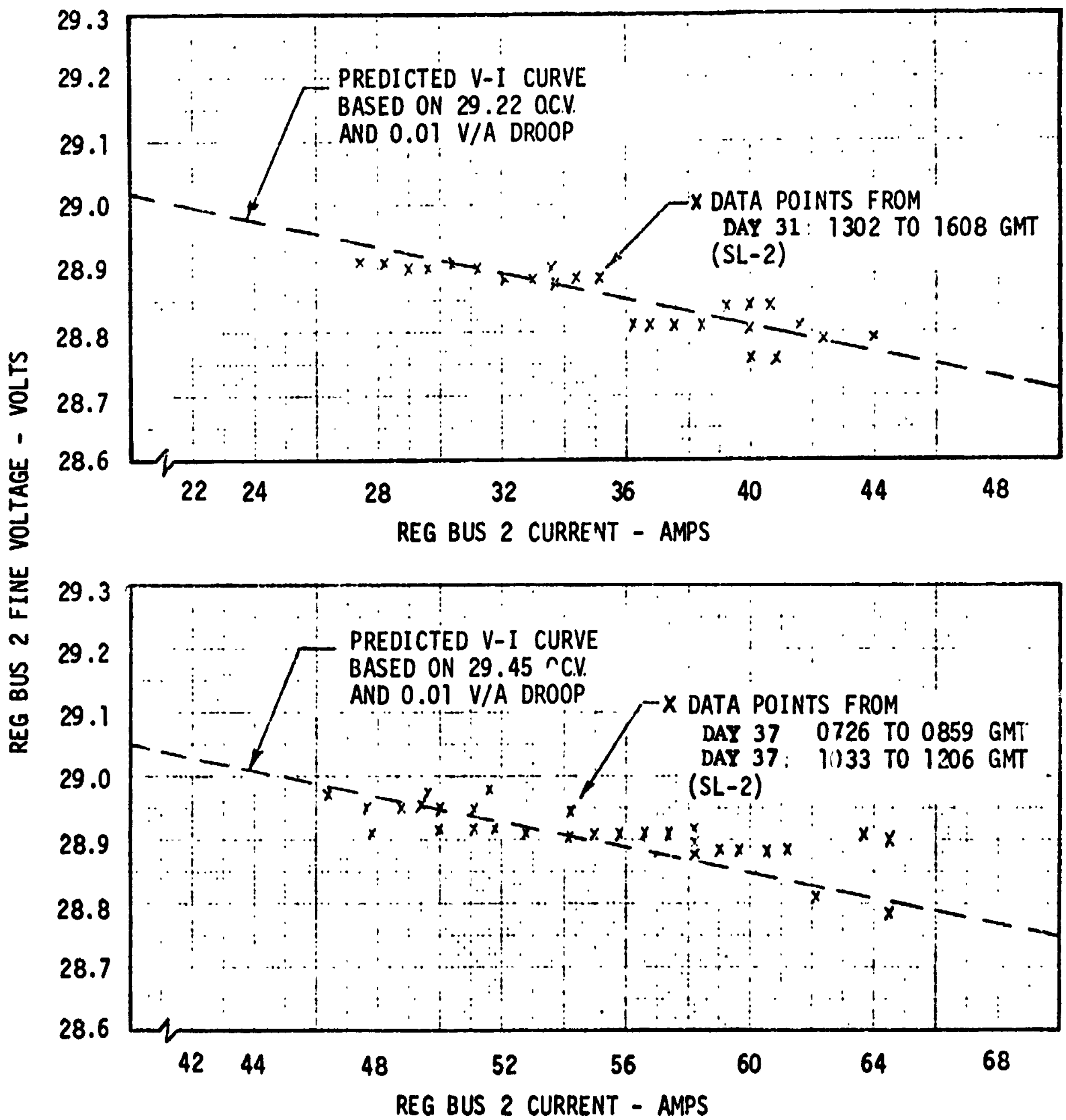


Figure 7.34 AM Bus Regulation (Typical)

3 Efficiency. For the operating conditions through the end of SL-2, the voltage regulator efficiency was better than 93%. Accurate calculation of the actual efficiency levels from flight data was not possible for the following reasons: 1) direct measurements of the voltage regulator input voltage and output voltage and current were not available so that indirect measurements and an output current estimate were used; 2) the accuracy limitations of the telemetry parameters used resulted in a large uncertainty in calculated values; and 3) the small value of the IR type losses involved. Voltage regulator temperatures in the range from 40°F to 60°F were recorded by telemetry throughout the mission. Temperatures in this range certainly indicated normal operation with no overheating or efficiency problems.

4 Power Module Operation. The AM Voltage Regulator contained five redundant power modules which satisfied the high reliability requirements. Each module operated successively as the output current demand was increased by a 13 ampere increment. During DAY 37 the Reg Bus load was great enough, approximately 15 amperes per PCG, that two power modules in each regulator were required to operate. The fact that the discharge currents for batteries associated with the same Reg Bus remained nearly equal and that no adjustment of the Fine Adjust potentiometers was required during SL-2 demonstrated that at least the first two power modules in each voltage regulator operated satisfactorily.

During most of SL-3, the AM load was such as to exercise only the first module of each voltage regulator. However, there were several instances, such as DAY 128 in which the load was sufficient to exceed 13 amperes per regulator and thus also required the operation of the second module in each regulator. Observation of the battery discharge currents indicated proper operation of the first two modules at these times. An apparent short on the ATM TV Bus 2 on DAY 83 at 0320:21 GMT resulted in a load of greater than 200 amperes on Reg Bus 2. This meant that four and possibly five of the modules in each voltage regulator did operate for a period of approximately 3 seconds.

The bus voltages were adjusted approximately two volts below their normal settings per the modified SL-3 AM EPS shutdown procedure. These regulated bus voltages were maintained for all input voltage levels and all bus loads. The regulator temperature telemetry parameters indicated no temperature or efficiency problems. Battery discharge currents indicated continued proper load sharing between regulators.

(3) Power Distribution. All elements of the AM/OWS Power Distribution Systems functioned as designed during the entire

mission. All required switching operations were successfully accomplished, power transfer and load sharing between EPS systems occurred when and as commanded, and all protective devices operated as designed. The four major elements of the Power Distribution Systems are:

(a) Switching. The following successful AM Power Distribution sequential control operations during SL-1/SL-2 were vital to the success of the Skylab electrical system, in light of the damage incurred and operational stresses imposed during the early days of the mission.

Activation of sequential buses, and activation and deactivation of deploy buses in response to OWS-IU commands. These were one-time operations during the sequential portion of SL-1.

Closing of Reg/Transfer bus ties in response to AM DCS commands. This operation was performed during SL-1 to parallel the AM and ATM electrical power systems for the first time in flight.

Deactivation of sequential buses in response to manual control switching by crew. This was a one-time operation during SL-2 only.

In addition to the above, the following operations were performed:

Changing electrical single point ground connection, for each manned phase, from AM to CSM, and from CSM to AM in response to crew manual switching of the Electrical Ground Control. The change from AM SPG to CSM VGP was accomplished after each CSM docking and umbilical connection and during SL-2 activation. The change back to AM SPG was accomplished during each deactivation prior to CSM undocking.

Activation and deactivation of EREP buses in response to manual control switches located in the MDA. These switching operations were performed throughout the missions in conjunction with all EREP operations.

(b) Circuit Protection. The AM/OWS Power Distribution System utilized parallel circuit breakers on the power transfer feeder wires from AM to CSM; between AM and ATM, and from Airlock to OWS and within the OWS. There were also two circuit breakers interconnecting the Reg buses. There was only one unscheduled opening of circuit breakers, and it occurred during SL-1/SL-2. Feeder circuit breaker 2 for OWS bus 1 was opened by an inadvertent crew action but was reclosed without any problems. Scheduled operations of

Transfer/CSM feeder circuit breakers and Reg Bus tie circuit breakers were successfully accomplished. These operations were in conjunction with the procedure for paralleling and unparalleling the CSM power system and the AM/ATM combined cluster power system.

Other protective devices utilized included: circuit breakers for transfer current monitors and for power distribution controls; fuses for voltmeter circuits and Reg Bus adjustment circuits; and fusistors (fuse-resistors) in telemetry signal lines for AM Bus parameters. There were no unscheduled operations of any of these circuit protective devices during the mission. Scheduled operations of the circuit breakers for the Power Distribution controls during activation and deactivation periods were successful in all cases.

(c) Power Transfer. Prior to Solar Array Wing #1 deployment, the AM Power Conditioning Groups were unable to supply power to the AM Reg Buses because of the absence of solar array power. The AM/OWS power distribution systems were used successfully during all mission periods to receive and distribute ATM electrical power. The AM EPS Control Buses were kept powered by closing selected PCG output controls to allow ATM power to each of them by way of the AM Reg Buses. Power transfer during SL-1/SL-2 was as high as 3200 watts from the ATM Buses to the AM Reg Buses. This power transfer capability contributed to the successful continuation of the mission until Solar Array Wing #1 could be deployed. Actual power transfer values for the entire mission are detailed in the system performance section of this report. On DAY 216, a short occurred on the ATM load bus 2. The power provided to this short by the combined AM/ATM power system was sufficient to clear it within three seconds. Accurate analysis of the condition during such a limited time span was difficult, however, rough calculations indicate that approximately 9,000 watts was transferred from the AM Reg buses through the AM transfer buses to the ATM buses. The Reg/Transfer Tie relays remained open throughout the SL-3/SL-4 storage period so no power was transferred between the AM and ATM electrical power systems.

(d) Load Sharing. Load sharing between the AM and ATM electrical power systems was controlled by the Reg Adjust Bus 1 and Bus 2 potentiometers. These potentiometers were adjusted a number of times throughout the entire mission and in all cases the desired AM and ATM EPS load levels were achieved.

Prior to SL-1 launch, both Reg Adjust potentiometers were set for an actual open circuit voltage (OCV) of 29.3 V on the Reg buses. This setting was the calculated setting for the desired AM/ATM load sharing when the two systems would be paralleled by DCS commands during the SL-1 mission phase. Inflight adjustments are also referenced to OCV settings by taking the sum of the Reg bus voltage, and the PCG total current times the Reg bus voltage droop (0.01 volts per amp) as being the approximate OCV value. There were no known inadvertent operations of the Reg bus potentiometers during SL-2.

During the SL-3 mission, one inadvertent adjustment of a Reg Adjust potentiometer occurred, when on DAY 109, an astronaut's pant cuff apparently caught on the Bus 2 potentiometer knob and resulted in a CCW rotation which increased Reg Bus 1 current to 61.3 amperes and decreased Reg Bus 2 current to 18.7 amperes. The system imbalance was quickly corrected by adjusting the Bus 2 potentiometers CW for equal PCG total currents. Reg Adjust Bus 1 and Bus 2 potentiometers were adjusted a number of times throughout the SL-4 mission, primarily in conjunction with EREP and Kohoutek passes.

(e) Controls and Displays. The onboard controls were located on STS Panel 205 and the onboard monitors were located on STS Panel 206.

Control usage from SL-1 launch to OWS SAS deployment, was by means of both DCS commands and crew switch actions. The low solar array power available to the PCGs was the general reason for the control switching that was performed. The solar array output switches were cycled between their normal and alternate PCGs several times. This was done as a means of increasing power to a single PCG so its battery could be charged, and as a safety measure to preclude low power inputs to PCG equipments. The batteries switches were used to turn the batteries off and on as required to charge when possible and preclude discharging the rest of the time. The batteries were also turned on several times so the PCGs could act as backup for the ATM EPS. The charger switches were cycled in conjunction with the solar array output switches for analysis purposes and to protect the battery chargers from low solar array power operation. The PCG output switches were cycled off and on when the PCGs were acting as backup for the ATM EPS. The discharge limit switches were placed in their inhibit positions on DAY 25 and returned to auto on DAY 26. This was done as part of the OWS solar array wing deployment activities so the PCGs could supply power, if necessary, even if the battery SOCs went below 30%.

All telemetry signals and onboard displays provided sufficient parameter information for operation and analysis throughout this period.

After the deployment of the OWS solar array wing, the controls were used to return the PCGs to their normal configuration. No subsequent control operations were required during the remainder of this mission. All monitors provided satisfactory information with the exception of the SAS #4 current monitor. The problem associated with the SAS #4 current monitor is discussed in detail later. The work-around method developed allowed satisfactory evaluation of all parameters.

All required control switching during SL-3 was accomplished successfully. All telemetry and onboard monitors provided satisfactory and sufficient parameter information for operation and analysis throughout the SL-3 manned mission. The SAS #4 current monitor anomaly, from SL-2, remained unchanged for the remainder of the mission.

Most of the control switching during SL-3 was associated with the capacity discharge testing of PCG batteries 6 and 8 on DAYs 105 and 106, respectively. The discharge limit command for PCG #3 was also used several times during this period in conjunction with EREP passes. The status light switches and the battery charge selector switch (associated with the % SOC meter) were also used successfully by the crew for periodic status checks on the AM EPS power system.

The first usage of a fine adjustment potentiometer occurred during the SL-3 mission. Optimization became desirable during SL-3, because EREP passes were scheduled at the rate of one to two per day over an extended period, toward the end of the SL-3 mission. This high EREP activity period also occurred during a period of low beta angle attitudes where both EPS system power capabilities are at their minimum.

Analysis of flight data showed that battery characteristics were very similar for the eight batteries. Therefore, the pot adjustments were required to balance out the effects of array shadowing. The ATM array shadowed one module each on SAG #5 and #8 and two modules on SAG #6. The effects of the module shadowing was that PCGs #5, 6, and 8 received less solar array power and could not recover from a DOD equal to the other 5 PCGs in the same amount of charge time. Based on the SI power capability definition, therefore, PCG #6 limited the allowable DOD to the energy balance value, thus none of the other PCGs could operate at full capability. The amount of adjustment for the Fine Adjustment pots were determined by using flight data and computer simulation programs. Pot #7 was not adjusted because PCG #7 was sharing equally with PCGs #1 through #4 and had the equivalent solar array input.

Pots #5, 6, and 8 were adjusted to cause their PCGs to supply 0.5 amperes of battery discharge current less than PCG #7 to compensate for each shadowed SAG module associated with it. To maintain this configuration as the two Reg bus pots were adjusted for AM/ATM load sharing at subsequent times, it was only necessary to adjust Reg bus pot #2 so that PCG #7 discharge current remained equal to PCGs #1 through #4.

As a result of the adjustments described above, all batteries returned to a fully charged state (100% SOC) at very close to the same time in a daylight period. Therefore, no one PCG, despite differences in available input power, limited the SI power capability. A more optimum power capability was therefore achieved by use of the fine adjustment potentiometers.

Due to increased demand for power outlets, power to MDA loads was supplied from higher power accessory outlets in the OWS forward compartment via two series connected 15 foot long utility cables for the remainder of the mission.

No control operations were required during SL-3/SL-4. All monitors performed satisfactorily with the exception of telemetry parameter battery #5 voltage, which shifted slightly higher on DAY 165 through the end of this period.

Telemetry monitors performed satisfactorily throughout SL-4, with the exception of, the SAS #1 current, Battery #1 through #8 coarse currents, Battery #1 temperature, and EPS control bus 1 and 2 current monitors. A T/M discrepancy caused erratic performance on these parameters from DAY 216 through the end of mission. The SAS #4 current telemetry monitor anomaly, described for SL-2, remained the same through the end of the mission. Fine adjustment potentiometer #7 was adjusted CCW slightly to equalize the battery #7 discharge current with that of Battery #5 and Battery #8. End of mission battery testing required the operation of many relay circuits which had seen little prior use. No problems were experienced as a result of this activity which followed a long period of dormancy.

Throughout the entire mission the following facts became obvious:

The crew did not encounter any static discharges.

No known EMI related problems existed.

Power was continuously supplied at voltages between 24 and 30 Vdc as required.

(f) Tracking and Docking Light Operation. The tracking light subsystem operated for each mission. SL-2 rendezvous operations required them for three hours and two hours, respectively, on DAY 12. During rendezvous, the Skylab was in a 50° pitch-up attitude for thermal control. The 130 nautical mile acquisition range, reported by the crew for both systems, was considered very satisfactory in view of this off-nominal viewing angle. The docking lights were successfully operated from the terminal phase of the rendezvous and remained operational until docking, about 1.5 hours, during mission. The tracking lights subsystem were operated successfully during the SL-3 rendezvous on DAY 76. They were activated at 14:23 GMT and were first reported by the crew at the 390 nautical mile range, which is in excess of the expected range.

Rendezvous for SL-3 and SL-4 was conducted with the SWS in a solar inertial attitude because of the reduction in AM/OWS power-generating capability as a result of loss of one OWS SAS wing. The solar inertial attitude caused some off-nominal look angles for the tracking lights, resulting in some predictable periods of loss of contact between the CSM and the SWS.

During the SL-4 rendezvous on DAY 187 they operated for approximately four hours. No indication was reported by the crew as to when the tracking lights were first sighted.

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b. ATM.

(1) Solar Array. SL-1 liftoff occurred on May 14, 1973 at 17:30:0.20 hours GMT. ATM solar array deployment took three minutes and was completely successful. Twenty-eight minutes after liftoff the ATM solar array wings were deployed, locked, and operational.

The loss of OWS SAS power, until DAY 25, reduced the overall cluster electrical power system capability, and the loss of the meteoroid shield permitted excessive solar heating internal to the OWS itself. To reduce the thermal heating on the OWS, the cluster was operated in a variety of non-solar inertial attitudes for the first 13 days. Knowledge of the exact off-pointing angles and, consequently, consistent ATM SAS data was unavailable for this period. (The APCS could not compute the sun pointing angles when the sun sensor was pointed more than 25^{o} away from the sun.) Approximations of the attitude were computed using a cosine function for SAS output and the SAS temperature. This unusual use of the ATM SAS, between DAY 1 and DAY 12, to determine the spacecraft attitude, assumed that certain panels had not degraded. Data indicated that the attitudes calculated were within a few degrees of the actual attitude.

The orbital attitude of the cluster between DAY 1 and DAY 12 resulted in many of the ATM Solar Panels exceeding the -65^{o}C lower limit of the qualification tests by 15^{o}C or more. The exact number of cycles that the lower temperature limit was exceeded was not known. The ATM solar panels were not designed to withstand temperatures of -70^{o}C to -80^{o}C, because at these low temperatures, the stresses on a solar cell interconnect increase rapidly with small changes in temperature. This severe exposure may have significantly reduced the electrical circuit reliability for the solar cells.

A specialized computer program (SEPSA) was used to determine solar panel degradation. Input variables included the day of year from which the solar distance is calculated, and the telemetered values of current, voltage and temperature for each panel at a particular orbital time.

The original array requirement to deliver 10480 watts at 55^{o}C at the beginning of mission (BOM) at zero beta angle was met by the ATM solar array. Based upon a prelaunch predicted SAS performance degradation from all causes, of 8.8% at the end of mission (EOM), the required average of 9558 watts at EOM was derived. SAS performance was analyzed and Figure 7.36 shows an available average array power of between 11886 watts and 13000 watts at 28^{o}C and 140 mW/cm^{2} solar intensity.

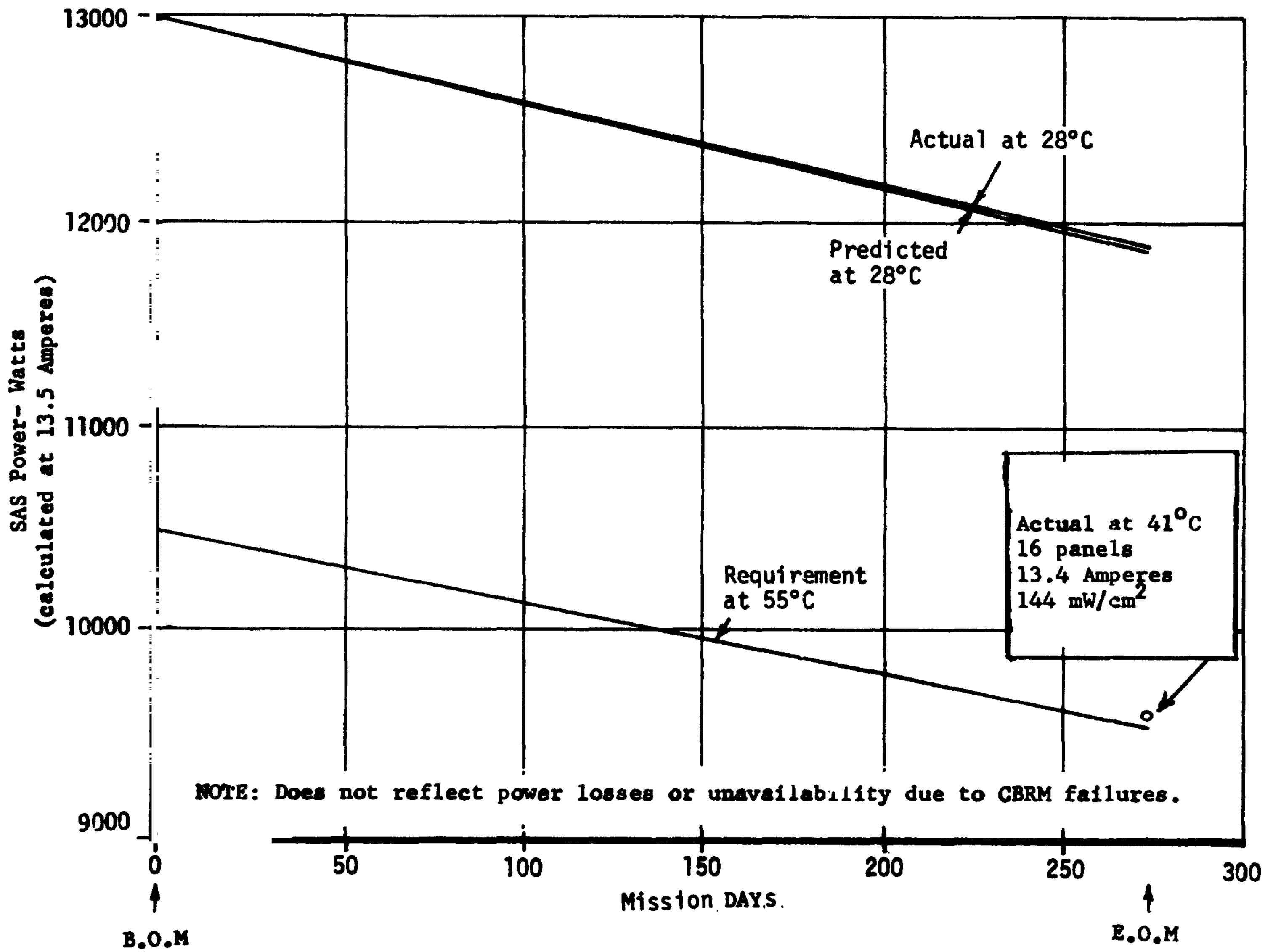

Figure 7.36 ATM Solar Array Performance Normalized at an Intensity of 140 mW/cm^2

Solar Array panel voltage and current data were evaluated for solar inertial orbits at beta angles from 0° to 73.5°. At low beta angles, the SAS was exposed to the sun approximately 61% of the time and the CBRM batteries had their highest DOD at high bus loads (for solar inertial attitudes); thus, at low beta angles the SAS provided maximum power for longer periods.

At beta angles above 69.5°, continuous sunlight orbits occur, and battery charge/discharge cycles do not occur, and only small variations occur in SAS voltage, current, and temperature.

Figures 7.37 and 7.38 show typical solar array panel voltage and current profiles for DAYs 42 and 97, respectively. Data for DAY 42 was included to illustrate high beta, continuous sunlight, solar panel characteristics. Figures 7.39 and 7.40 for DAY 120 show voltage and current profiles during one orbit of low beta operation.

(a) Degradation. Of the eighteen panels, fifteen were in operation continuously after SL-1 launch. CBRM 3 (Panel 713A4) ceased operating on DAY 17 when its regulator failed, and remained off. Insufficient data points existed to establish a degradation trend for panel 713A4. CBRM 5 (half panels 710A1-713A1) was not operated after DAY 123 when its charger malfunctioned (except for EREP maneuvers late in the mission). These panels were not included in the determination of the average degradation rate.

CBRM 15 (Panel 713A5) was inoperable for an extended period early in the SL-1/2 mission. However, sufficient data was obtained to establish a degradation trend for this panel.

An unusual phenomenon occurred on CBRM 17. The CBRM regulator output current was highly erratic, as observed on DAY 24. Analysis indicated that the CBRM regulator was receiving full power from about ten minutes into each orbital night until sunrise. An intermittent short to negative on solar panel 17 (710A4) allowed no power to be available to the CBRM during the daylight portion of each orbit. The solar cell, when cooled down (i.e., ten minutes into night), acted as a diode to block the short circuit condition. This condition continued until DAY 151 when it disappeared and did not reappear.

Panel 711A5 (CBRM 13) showed a consistent trend of degradation after launch of SL-1. This panel provided six percent less power than predicted at launch and continued to degrade at a rate of 2.8 percent per month.

BETA ANGLE = 73.5°

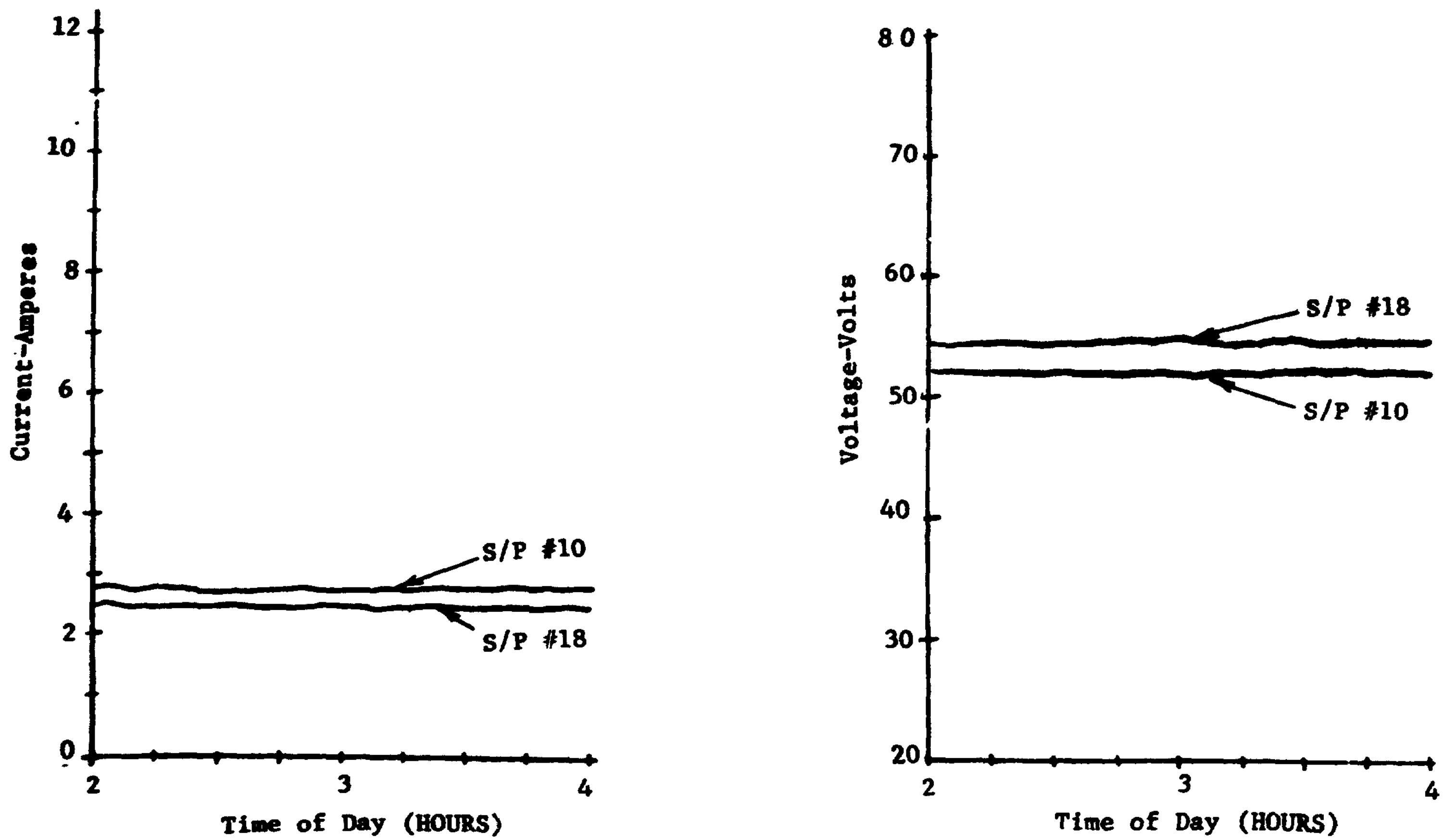

Figure 7.37 Current and Voltage Profiles for Solar Panels 10 & 18 ——DAY 42

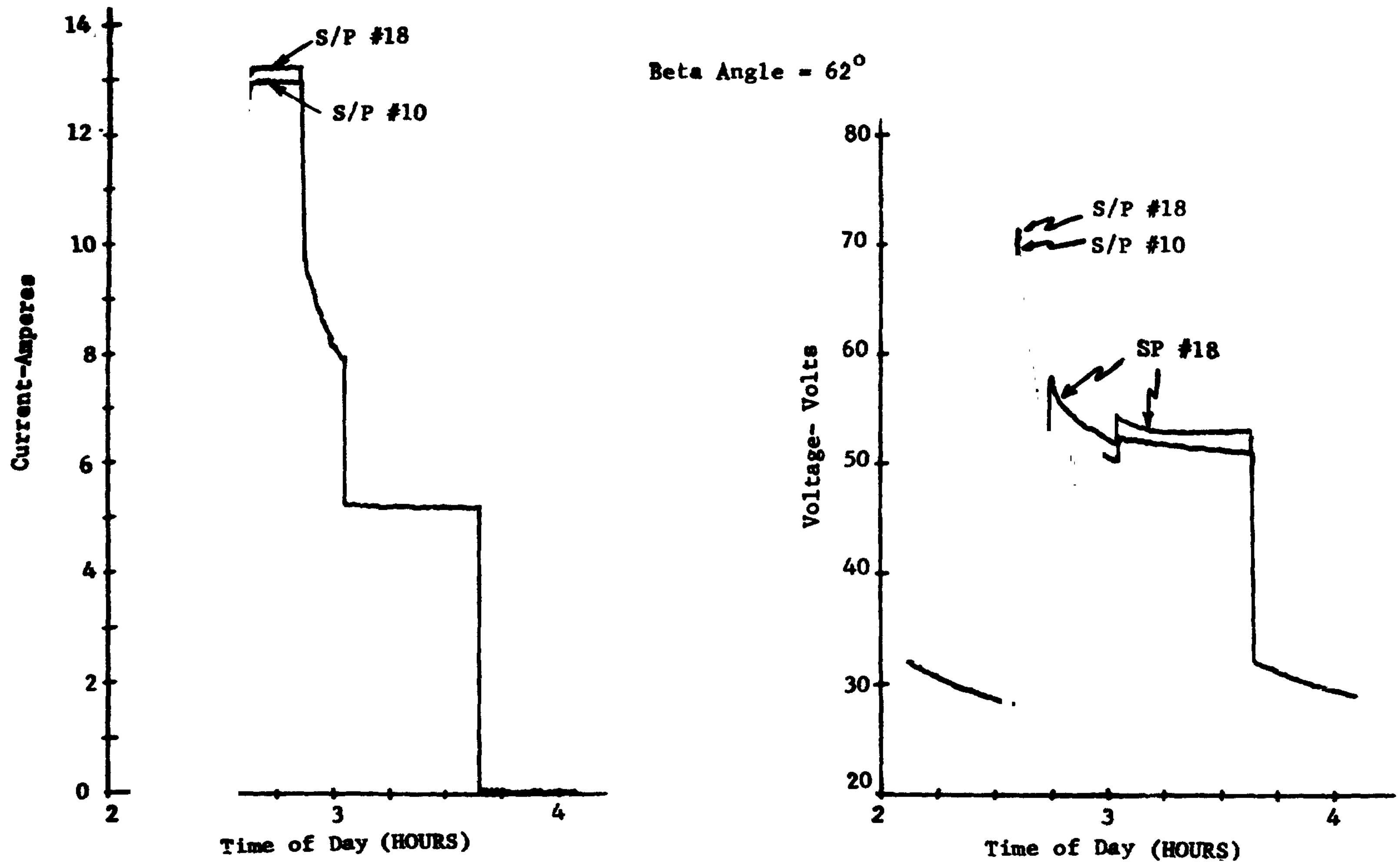

Figure 7.38 Current and Voltage Profiles for Solar Panels 10 & 18 —— DAY 97

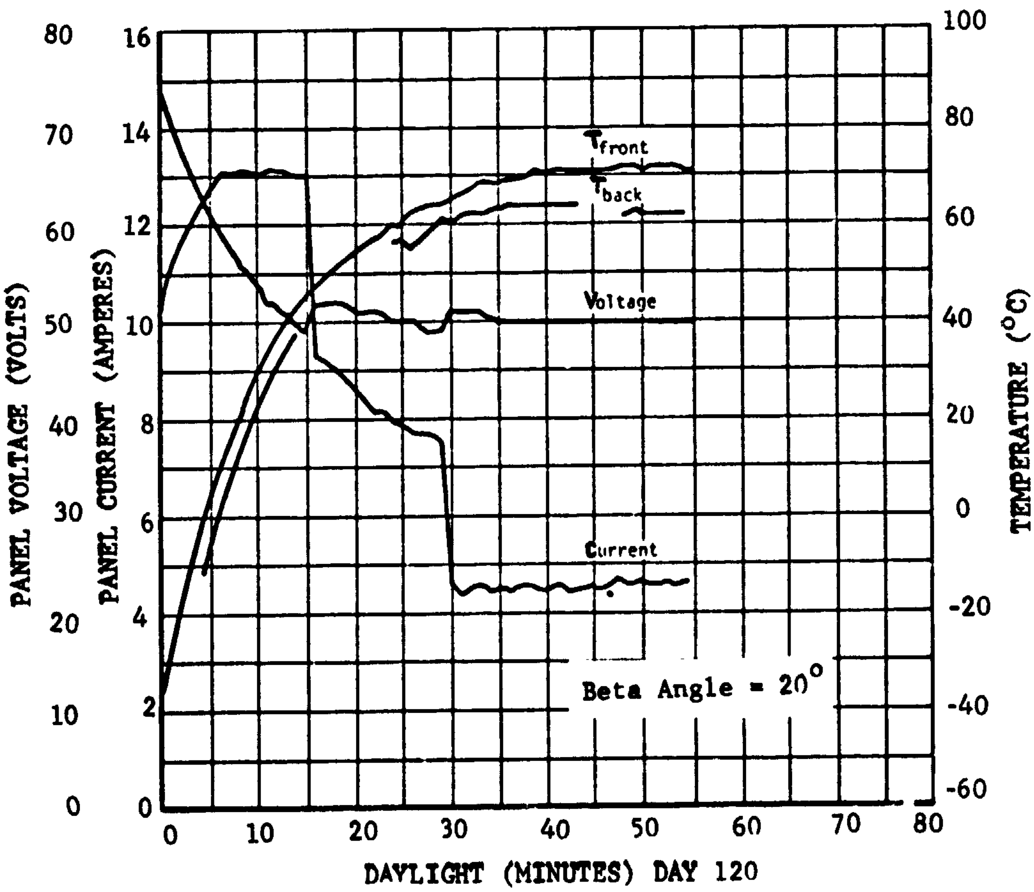

Figure 7.39 Profile of Panel Current, Voltage, and Temperature for a Typical ATM Solar Panel - Panel 712A3, No. 10

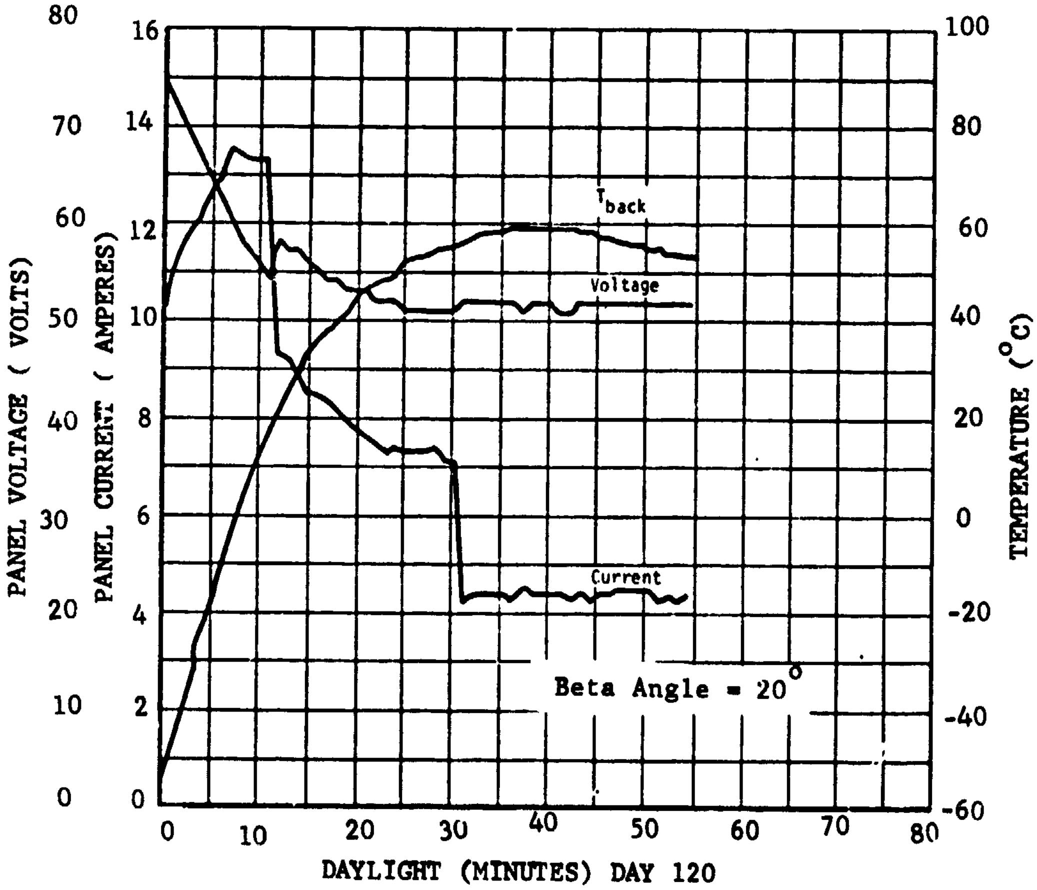

Figure 7.40 Profile of Panel Current, Voltage, and Temperature for a Typical ATM Solar Panel - Panel 710A5, No. 18

Panel 711A2 (CBRM 8) started the SL-1 mission with a power deficit of between four and six percent. The first solar inertial pass following SL-2 docking from which reliable data was available (DAY 14) showed an additional abrupt power loss of six percent.

Solar panel 711A3 (CBRM 7), which was adjacent to Panel 711A2 showed similar behavior. Initially, the power capability was four to eight percent greater than predicted by ground test data. On DAY 14, this panel indicated a ten percent power loss or 3.5 percent below predicted.

The decrease in capability of the degraded solar array panels was observable in the CBRM operation. Degraded panels were required to supply high currents for longer periods in order to charge their respective CBRM batteries. These CBRM batteries cut back from the constant current mode to the constant voltage mode several minutes later than the rest of the CBRMs. This delay in recharging also varied depending upon orbital considerations, load, and the state-of-charge and condition of the battery. As the panels continued to degrade at expected rates, the delay in reaching cutback to constant voltage mode increased slightly.

Intermittent power losses on Panel 15 (713A5) were first observed and recorded on DAY 206. The step voltage changes which occurred seemed to be due to cyclic successive openings of as many as two modules on Panel 15. Figure 7.41 shows the voltage versus time for Panel 15 during a typical orbit on DAY 206. The SAS current during this time was constant. The first voltage step occurred at 28°C and was 1.6V. The second step occurred at 30°C and was 5 V. The cumulative effect of the two steps was the equivalent of a loss of two solar cell modules. This resulted in a power loss measured in the constant current range of operation (13.4 amperes) of approximately 13% for the panel (0.8% for the array). The orbit-to-orbit regularity of the change suggested a thermal-related making and breaking of a connection which intermittently open circuited the module. A plot of panel voltage versus temperature at constant current (Figure 7.42) further exemplified the problem on Panel 15. Notice the abrupt loss of voltage (power) at 28°C and 30°C. As can be seen from Figure 7.42 the anomaly occurred late in the orbit each time it occurred allowing normal battery charging and having no effect upon the mission during solar inertial operations.

The power capability status of the ATM array was assessed as of DAY 269 and compared with preflight performance measurements. The results are given in Table 7.IV. Based on the EOM status, the average degradation rate over the entire mission was 0.9 percent per month.

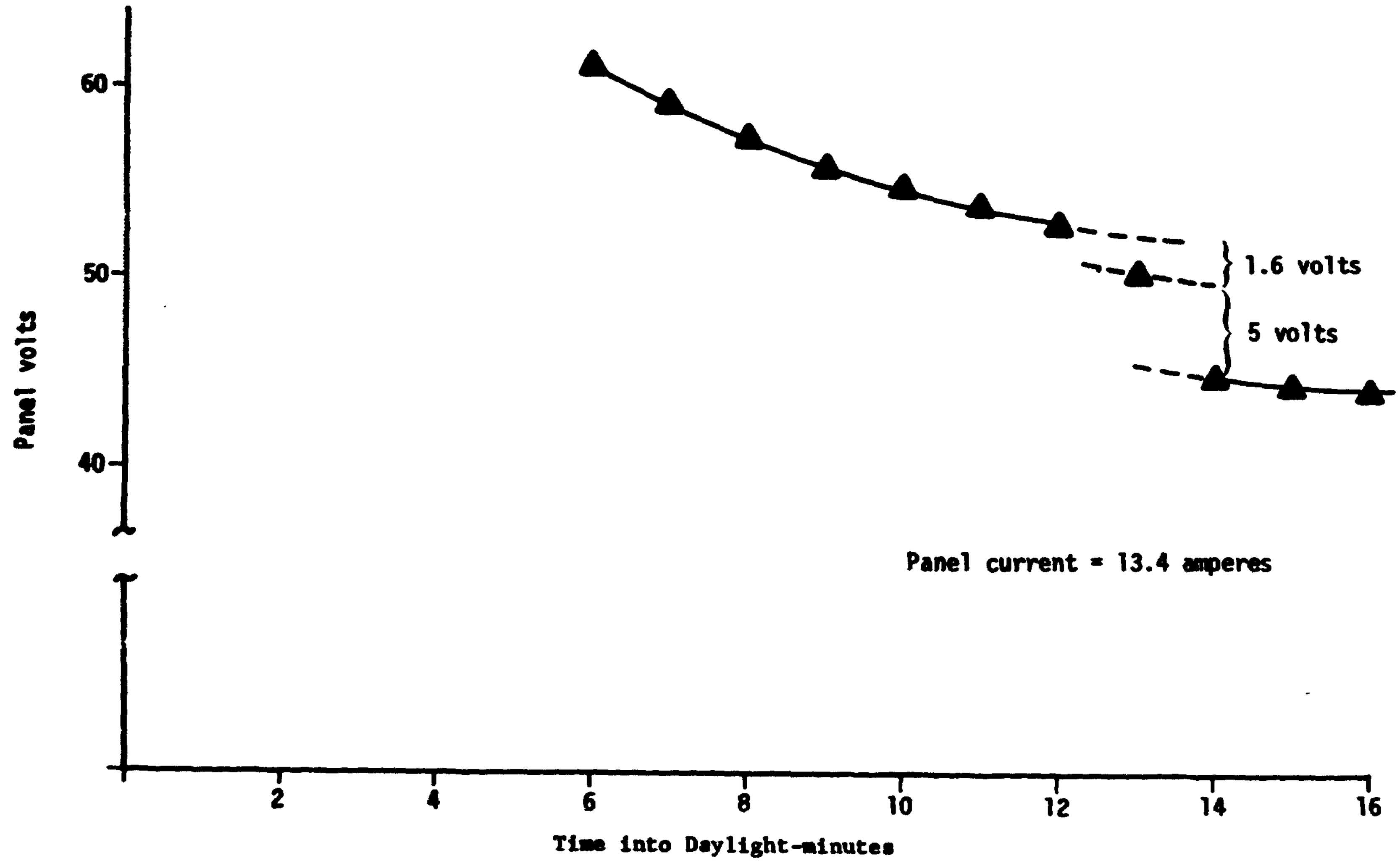

Figure 7.41 Panel 15 Voltage vs Time DAY 206

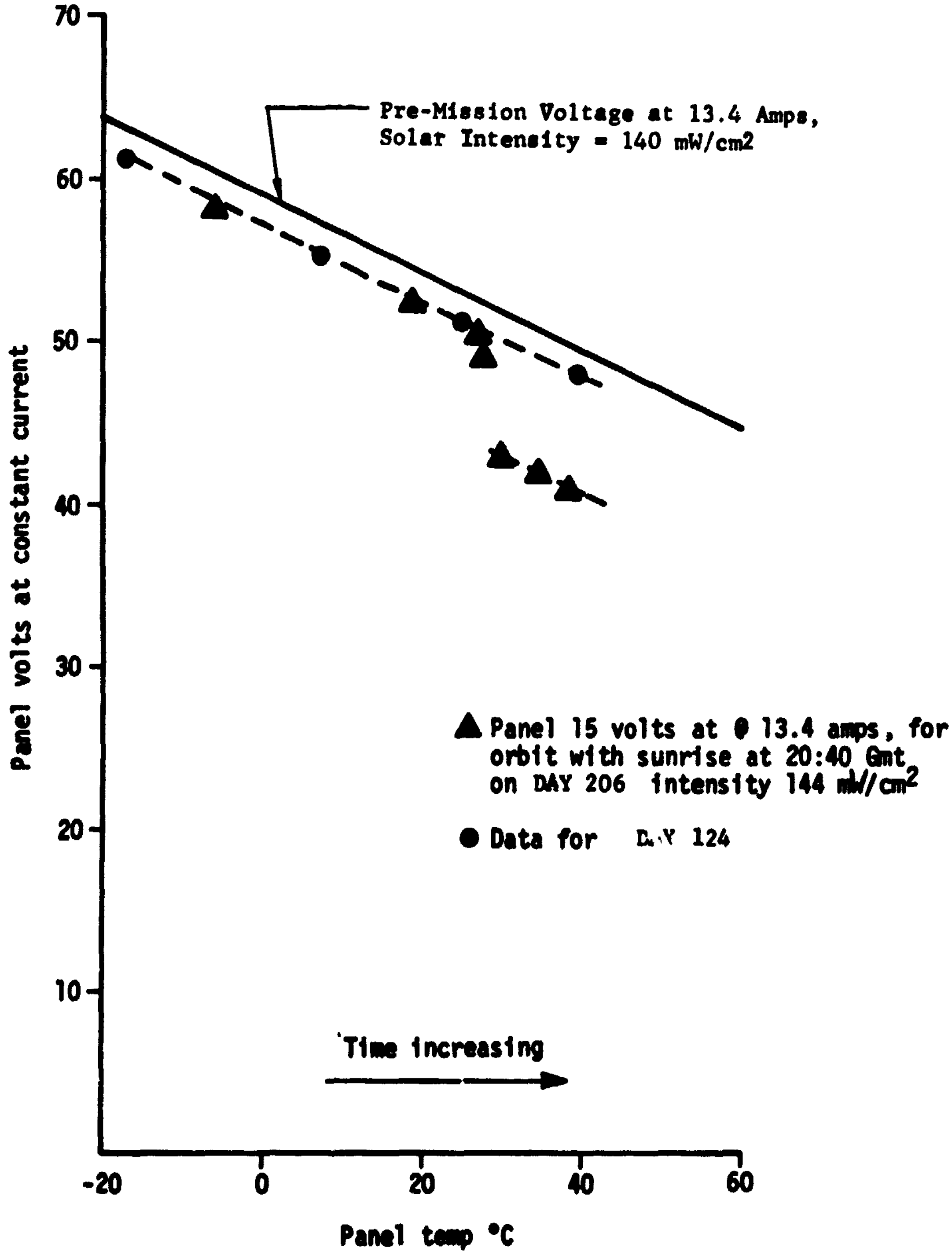

Figure 7.42 Panel 15 Voltage Comparison Showing Anomaly

The degradation shown by the ATM solar panels was caused by expected failure mechanisms such as micrometeoroid damage, radiation damage, and interconnect damage due to thermal cycling. In addition, the extremely low temperatures reached by the solar panels between DAY 1 and DAY 12, which often exceeded qualification test limits, could have affected the degradation rate for each panel, depending upon its location and thermal characteristics.

During SL-2 docking, flyaround and undocking maneuvers, and the SL-3 docking maneuver, the ATM solar array wings were exposed to engine plumes. While the individual exposures were short, the total exposure during these maneuvers was sufficient to cause concern. The accumulated exposure time has not been determined. Two major effects were caused by exposure to the plume: 1) contamination, and 2) flexing of the solar array wings due to mass impingement.

The abrupt losses of power of panels on or near the ATM telescope, indicated that the panel degradations probably were not the result of contamination.

Some discoloration of the S13G thermal paint on the underside of the wings was observed by the SL-2 crew. They reported that the wing undersides were darkest near the ATM canister, becoming lighter toward the wing tips. Darkening of the S13G could have caused a change in the thermal characteristics of the ATM panels. However, no effects resulting from the discoloration were observed.

Films taken during rendezvous, docking, and flyaround maneuvers, indicated that the wings flexed as much as plus or minus one foot as a result of being sprayed by the RCS engine exhaust. The mechanical stresses induced by this flexing on the ATM panels could not be determined with the measurements available.

(b) Thermal. Analysis of panel temperature transients during the mission showed that there was no appreciable change in thermal characteristics and thus no additional effect on ATM array power output capability. This was concluded from a comparison of temperature data early in the mission and late in the mission at the same beta angle and approximately the same solar intensity. The minimum beta angle and the largest temperature variation occurred on DAY 229. Figures 7.43 and 7.44 show panel temperatures for selected panels 7, 10, and 18 on DAY 229 and DAY 117. The largest variation on DAY 229 was seen to occur on panel 7's front surface and was from +79°C to −40°C and compared to the data on DAY 117 (+78° to −42°C) indicated no degradation of the thermal coating.

PARAMETER	UNITS	VALUE
Day	DAYs	269
Beta Angle	Degrees	+15
Revolution	Number	3874 *
Panel Current	Amperes (Fixed)	13.4 ± .3
Time after sunrise	Minutes	19
Direct solar intensity	mW/cm^2	144.1
Average panel temperature	°C	41
Power output, 16 panels	Watts	9596
Average degradation for 13 panels	Percent	8.6

Note: Three panels were not considered in the degradation calculation because of temperature transducer anomalies. Also, the solar array panels for CBRMs 3 and 5 were not on line and thus not considered.

* Solar panel date during this revolution was used to represent the EOM performance status of the ATM array.

Table 7.IV EOM Status - ATM Solar Array

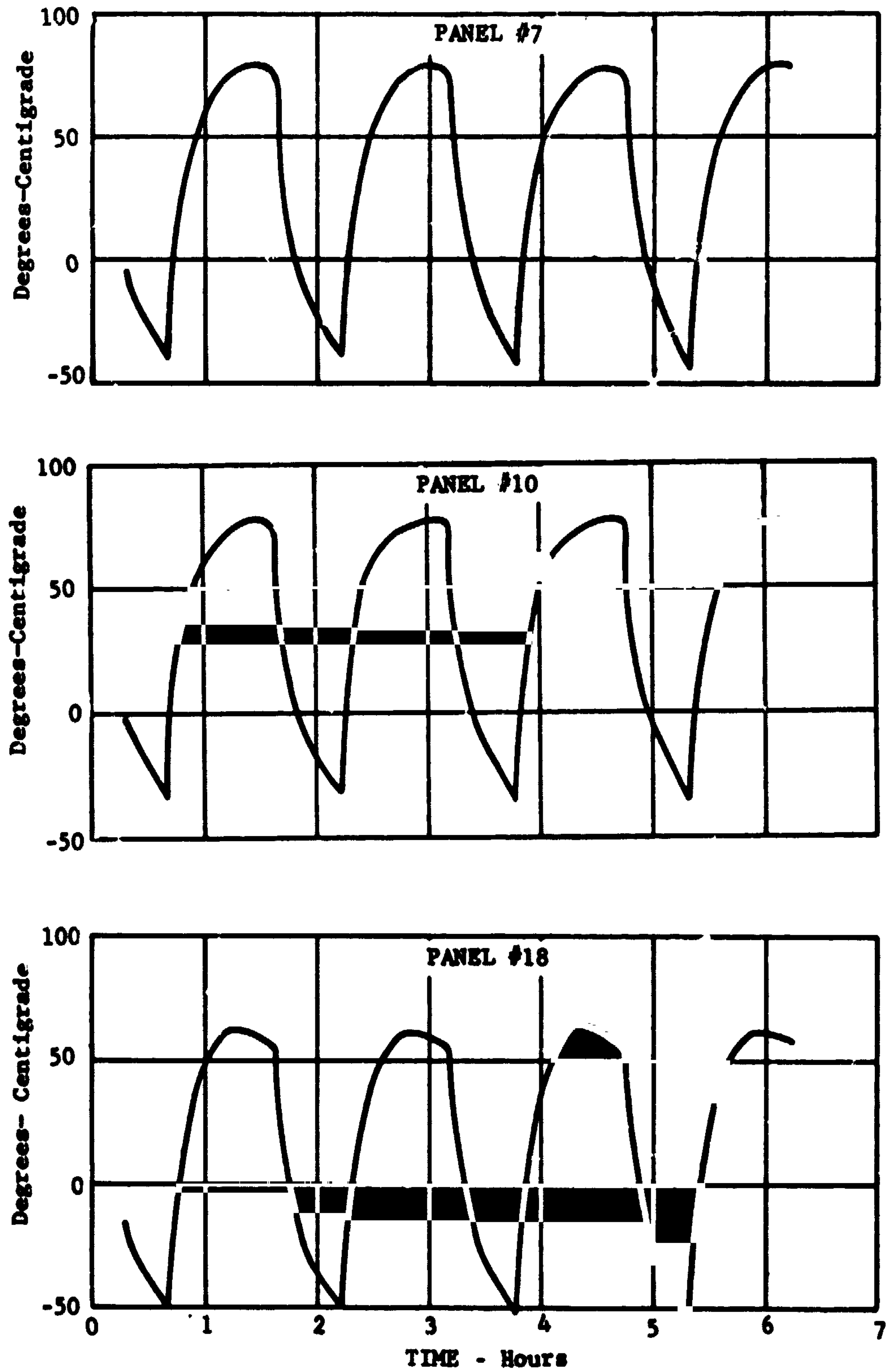

Figure 7.43 Temperature Profiles - Beta = 0° - DAY 229

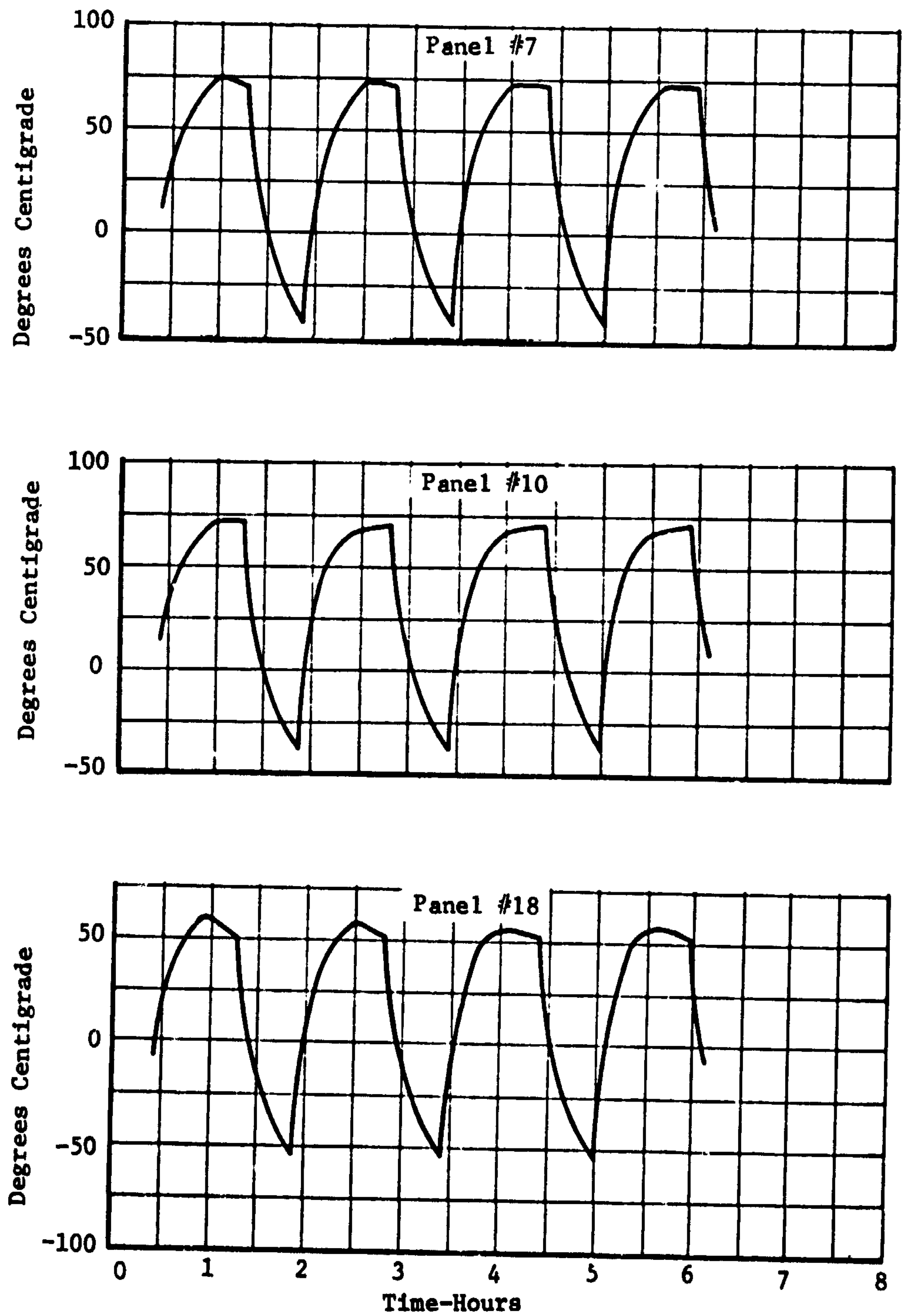

Figure 7.44 Temperature Profiles - Beta = 0° - DAY 117

As early as DAY 3, inconsistent temperature readings were observed. These observations indicated that the sensors on Panel 7 indicated a gradient of up to 40°C between the front and rear surfaces of the panel in contrast to gradients of seven to 13°C for the mid-wing panels of Wings 1, 3, and 4. Also, temperature time profiles during different orbits and mission times indicated that the backside temperatures did not agree with predicted data in most cases. Figure 7.47 shows a typical example for panel 18 on DAY 71.

The temperature profiles for DAY 100 (beta = 62°) and DAY 42 (beta = 73.5° or full sunlight) for Solar Panel 18 are included to show typical orbits at high beta angle. (See Figures 7.45 and 7.46.)

Two temperature transducers on panels 711A3 (CBRM 7) and 712A5 (CBRM 12) were either loose or operating intermittently.

Temperature measurement uncertainties continued to be a problem on SL-4. During the last 14 days of SL-4, two additional panel temperature sensors became faulty,necessitating estimation of true temperatures by use of indirect means. The faulty sensors were on Panels 713A3 (CBRM 2) and 711A5 (CBRM 13).

Panel operating temperatures generally did follow predicted transient patterns, but operated significantly cooler because of the absence of reflected heat from OWS SAS Wing 2.

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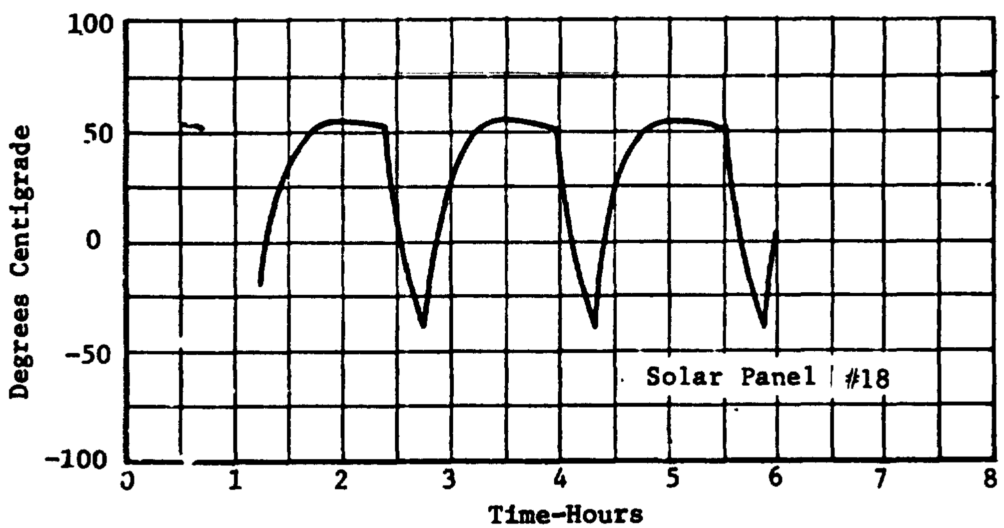

Figure 7.45 Temperature Profile - Beta Angle of 62° - DAY 100

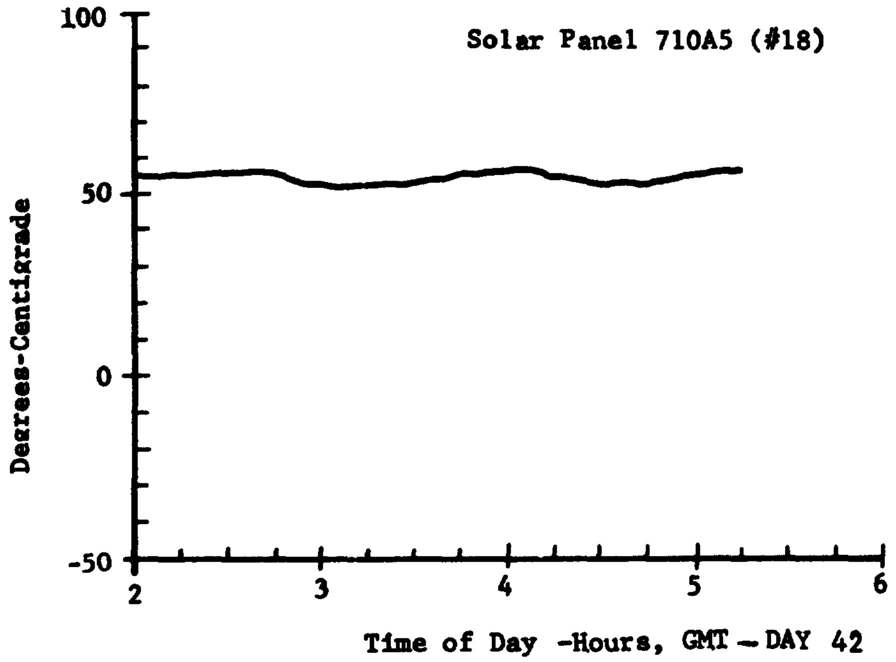

Figure 7.46 Temperature Profile - Beta Angle of 73.5

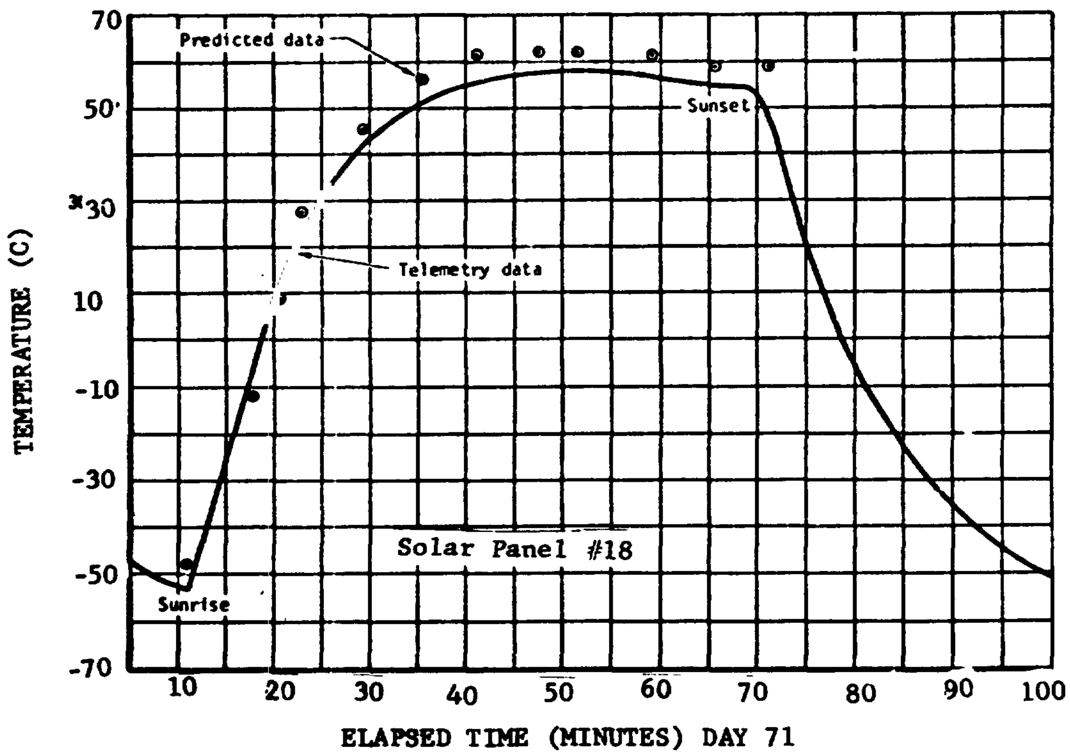

Figure 7.47 Comparison of Predicted and Telemetered Temperature Profiles for a Typical Panel During Solar Inertial Orientation

(2) CBRM. Each CBRM contained: a charger, to condition the solar cell array power and control battery charging; a battery, to supply energy during dark portions of each orbit; and a regulator, to condition battery or solar array voltage supplied to the ATM power buses. In addition, the CBRM contained automatic protection and control circuits, telemetry and onboard display circuits, and a battery heater control circuit. The CBRMs were normally controlled by ground command with astronaut control for troubleshooting, battery capacity tests, and general systems monitoring. Astronaut control was accomplished through switch operation from the ATM C&D console, although backup operation from the DAS Keyboard was available. Flag indications on the ATM C&D console alerted the astronaut to out-of-tolerance conditions. See Figure 7.58 for the layout of the flags. Table 7.V summarizes CBRM performance, in general, by parameter. The table compares requirements, ground test measurements, flight values, and predictions. Table 7.VI lists the commands and responses of the CBRM. Out-of-tolerance conditions caused applicable CBRM components to be automatically turned off. Table 7.VII lists the CBRM automatic response to malfunctions. No provision was made to automatically turn on components if the malfunction should correct itself. However, the component affected could be turned on manually or by command.

(a) Charger. The charger was a stepdown single-ended regulator which conditioned the inputs from the solar array panel to the level required for charging the battery while achieving maximum use of array power (see Figure 7.48). The charger senses solar array voltage and current, battery temperature, charge current, 3rd electrode voltage, and output voltage for charge control. The modes of operation of the charger are illustrated in Table 7.VIII.

See Figure 7.49 for charge characteristics of a typical battery. The voltage trip point (the voltage at which the charging mode is changed from constant current to constant voltage) was made relatively lower as the battery temperature rose (see Figure 7.50).

The average charger efficiency as calculated from data from DAY 205 was 92.5% after a 20% DOD. This compares well with the ground test data which showed the efficiency range from 92.9 to 94.3% over the entire load range.

The high efficiency of the charger can be attributed to the inherently high efficiency of a switching type charge regulator, combined with a circuit design, which allows drive current for the regulator power switches to be supplied to the load.

The depletion of battery power during the early off-sun pointing caused automatic battery disconnect, on DAY 12, of 8 batteries, including Battery 15. An unexpected regulator 15 disconnect occurred

Parameter	Requirement	Ground Test Data	Source of Data	In-flight Value
Battery Cycle Life	4000 Cycles Operation	Cycle life and temp data	Battery Cycle Test	4100 Cycles
Charger Efficiency	92%	92.9 to 94.3% Over the Load Range	CBRM Electrical ATP	92.5% @ 20% DOD (During Charge)
Regulator Efficiency	89% from 100 to 200W 85% at 400W	90.5 to 94.1% 84.0 to 86.8%	CBRM Electrical ATP	92.4% (During Day) @ 20% DOD 89.3% (During Night)
Charger Control of Battery V vs. T Characteristics	Specified Curves $\pm$ 150 mV	Specified Curves $\pm$ 100 mV	CBRM Electrical ATP	Ground Test Curves Used
Maximum SA Current (Charger On)	13.5 $\pm$ 0.5A	13.5 $\pm$ 0.1A	CBRM/Solar Panel Sunlight Testing	13.1 to 13.6A Average: 13.4A
CBRM Life	4000 cycles	8000 cycles	Life Test	4185 Orbits

Table 7.V CBRM Performance

Parameter	Predicted Value	Ground Test DATA	Source of Data	In-flight Value
Continuous Bus Power Capability of One CBRM/SA Subsystem (Worst Case SA) at Energy Balance	218 Watts at the bus.	227 Watts	CBRM Life Testing with Simulated Solar Array	Efficiency = 737 Solar Array to Bus. SL 1/2: Worst: #13:260 Watts Best: #16:310 Watts SL 4: Worst: #15:245 Watts #13:270 Watts Best: #16:305 Watts
Temperature Range of Batteries Under Hot and Cold Predicted Environments	$-10^{o}C$ to $+30^{o}C$	$-10^{o}C$ to $+30^{o}C$	ATM Prototype T-V Testing	SI: $0^{o}C$ to $15^{o}C$ Off Pointing: $30^{o}C$ Max
Power Mismatch Between CBRMs - Controlled by Power Share Circuits	5% for 100 W to 300W per CBRM.	3.5%	ATM Prototype T-V Testing	See Table 7.XII.

Table 7.V CBRM Performance (cont.)

Command	Signal Required	CBRM Response
Charger ON	24 to 31 Vdc, 18 to 60 milli-second (ms) duration.	Turns on charger; closes battery contactor and input contactor if they are not already closed.
Regulator ON	24 to 31 Vdc, 18 to 60 ms duration.	Turns on regulator; closes input contactor if it is not already closed; enables battery heater control.
Charger OFF	24 to 31 Vdc, 18 to 60 ms duration.	Turns off charger; opens battery contactor and input contactor if regulator is off.
Regulator OFF	24 to 31 Vdc, 18 to 60 ms duration.	Turns off regulator; opens battery contactor and input contactor if charger is off; disables battery heater control.
System ON	ATM system common.	Turns on charger and regulator; closes battery contactor and input contactor.

Table 7.VI CBRM Command System

Parameter and Malfunction	Malfunction Value	CBRM Component Turned Off			
		Charger	Battery Contactor	Regulator	Solar Array Input Contactor
Battery Voltage Low	26.4 V + 0.5, -0 V	X	X		
Battery Voltage High as Function of Temp.	See Figure 7.50	X	X		
Battery Temp. High	$50^{o}C + 0^{o}C, -2^{o}C$	X	X		
Battery Discharge Current High	25 A $\pm$ 1 A	X	X		
Regulator Output Voltage High	31.8 V $\pm$ 0.2 V			X	
CBRM Internal Reference Voltage Out of Tolerance	High: 15.2 V $\pm$ 50 mV Low: 14.8 $\pm$ 50 mV	X	X	X	X

Table 7.VII CBRM Automatic Response to Malfunctions

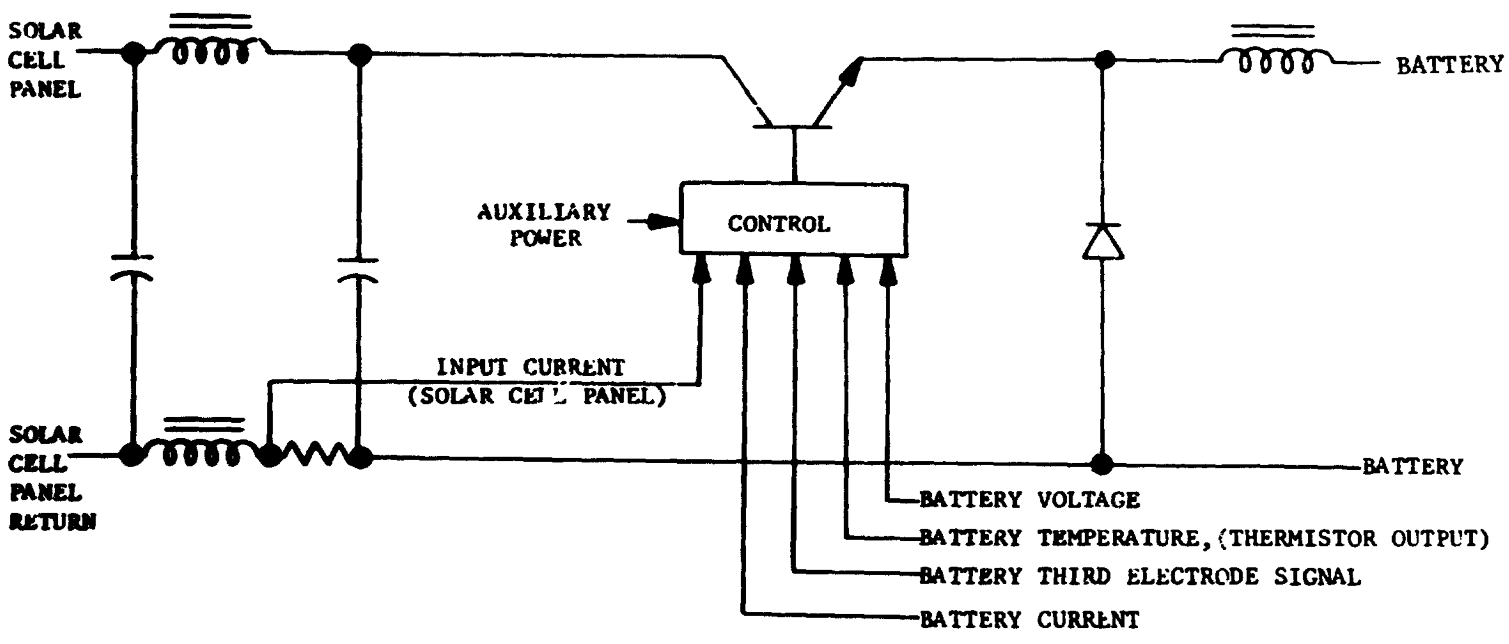

Figure 7.48 ATM Charger Simplified Schematic

Charger Operation Mode	Charger Output Condition: Output Voltage	Current Output	CBRM System Condition Required
Constant Current	Voltage level necessary to provide the current indicated in the next column.	15 $\pm$ 1 A	Solar panel power sufficient. Battery voltage and temperature are less than the trip-out thresholds as shown in Figure 7.50.
Constant Voltage	Voltage level is decreased by 0.85 $\pm$ 0.15 Vdc when battery voltage reaches trip back voltage (Figure 7.49) then controlled as a function of temperature.	Current as determined by the voltage.	Solar panel voltage $>$37.75 $\pm$ 0.25 Vdc. Battery voltage and temperature below trip-out voltage (Figure 7.50).
Charge-Off	0 Vdc	0 A	Solar panel voltage $<$ 37.75 $\pm$ 0.25 Vdc and/or battery third electrode signal indicates a fully charged battery.

Table 7.VIII CBRM Charger Operation Modes

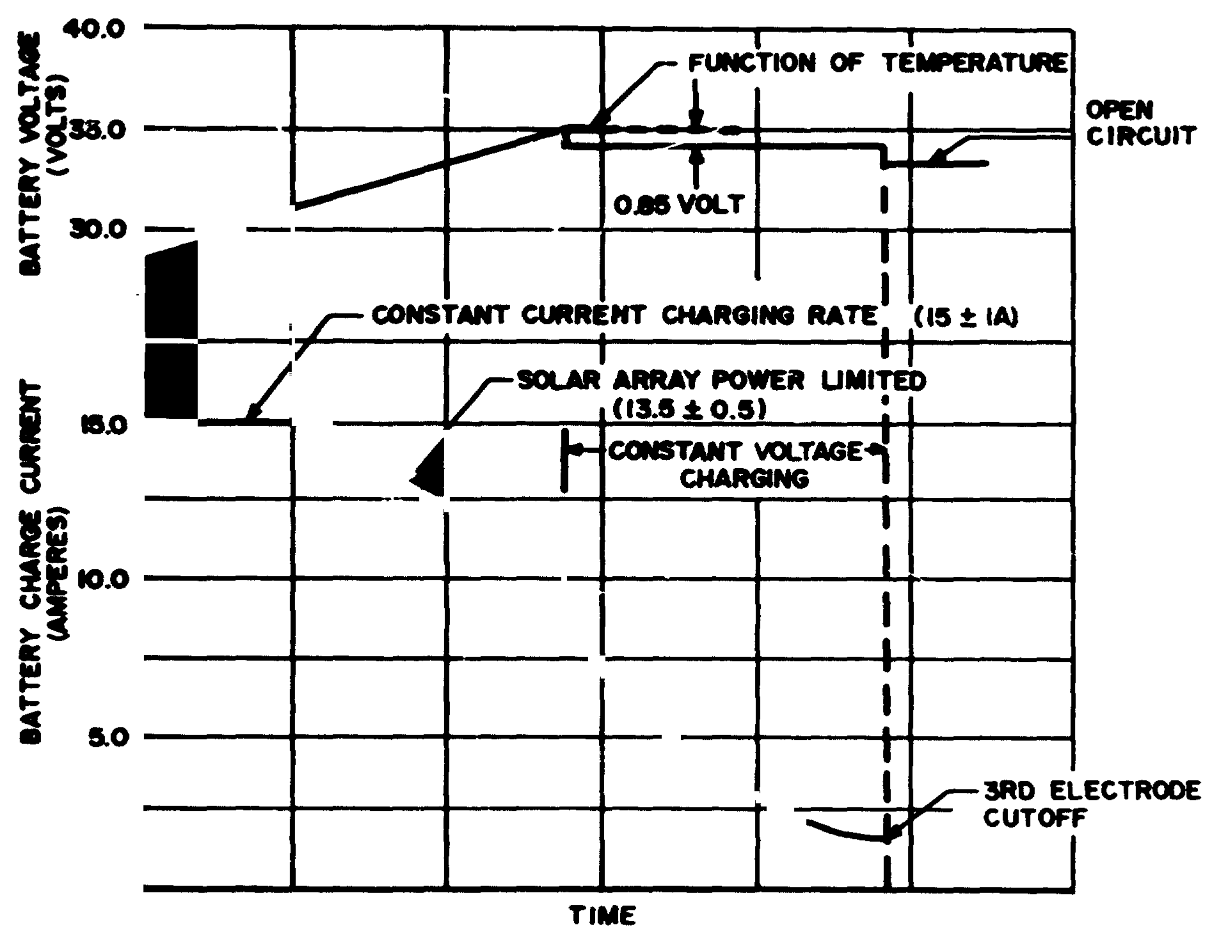

Figure 7.49 ATM Battery Charging Conditions

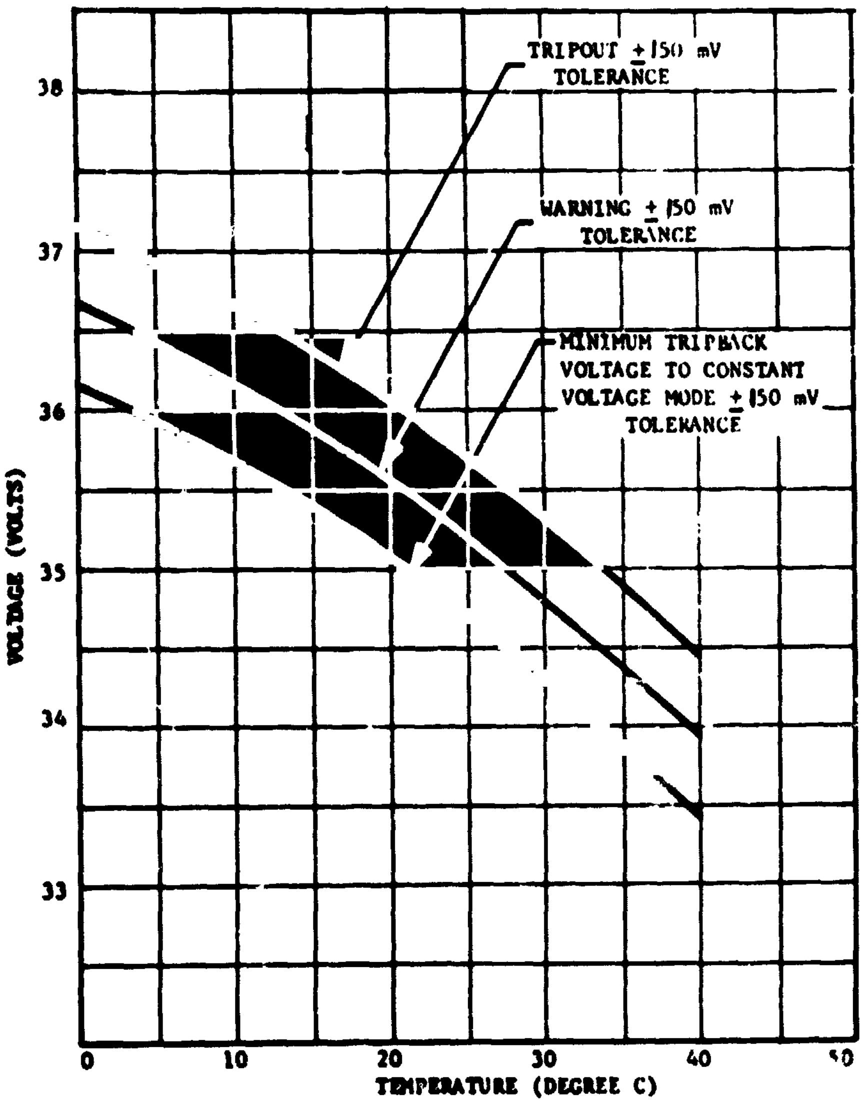

Figure 7.50 ATM Battery Charge Trip Voltage as a Function of Temperature

upon entry into sunlight. The low solar intensity of the SAS, combined with both battery and charger off caused the regulator to oscillate and to automatically trip off. The trip-off then caused the contactor to open between SAS and CBRM 15. The contactor then failed in the open position. The astronauts, during a scheduled extravehicular activity on DAY 37, struck CBRM 15 with a hammer to generate internal forces which freed the stuck relay and restored the CBRM to full operating capability.

No failures, anomalies, or deviations from normal performance were detected through the end of the first manned mission for the power stages, charge control logic, auxiliary power supply, or the battery sensing circuits of the chargers.

On DAY 123 the battery charger of CBRM 5 failed while charging the battery causing the battery to automatically disconnect because of overvoltage. The failure allowed the solar array power to feed directly to the battery without conditioning. The CBRM was not used during the remainder of the second manned mission, and a workaround was developed to combine CBRM 5 regulator and CBRM 3 charger and battery by use of jumpers. This modification was carried up by the third crew but was not implemented.

At the end of the third manned mission, in a power critical situation during Z-LV (EREP) operations, CBRM 5 was turned on to provide added power since the charger failure mode basically allowed the charge voltage to exceed the maximum programmed voltage by one volt. Automatic disconnect circuits terminated the charge at this point. CBRM 5 functioned under these conditions and maintained the battery operating parameters within their safe limits. Commanding was required to reconnect the battery and regulator after autodisconnect at sunset.

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(b) Battery. The ATM NI-CD batteries provided power for usage during the dark portion of every orbit of the Skylab mission. The batteries had a nameplate or vendor rating of 20 Amp-Hrs and the measured preinstallation measured capacity was 25 Amp-Hrs average for the flight batteries. After ATM solar array deployment all batteries demonstrated an ability to accept charge while exhibiting anticipated voltages.

After AM/ATM paralleling on DAY 1 at 19:27 and all AM PCG output power was disconnected from the Skylab buses at 19:30, the ATM power system provided all the power to the cluster buses until OWS Solar Wing 1 deployment on DAY 25. In this time period, the ATM batteries were managed such that energy balance was the goal. However, the batteries were allowed to go below energy balance during many orbits. Vehicle attitude was constrained such that the batteries were recharged before a poor (for solar array pointing) attitude was attempted again for thermal balance of the cluster. Because of the required thermal attitudes, CBRMs pointed toward the sun (CBRM #6, 7, 8, 16, 17, 18) experienced temperatures as high as 30^{o}C. Deepest discharges were observed on DAY 17 on the night portion of the orbit following the first EREP pass. CBRM Battery 11 had the highest DOD, 54% (10.8 AH removed). In this period four regulators had been shut off, and the remaining 14 batteries provided all of the required power. This situation also provided the maximum battery discharge rate that occurred in the Skylab mission. CBRM Battery 11 also had the highest discharge rate, discharging at a 14.2 Ampere rate. (The pre-mission maximum allowable rate was 20.0 amperes.) As a comparison, during KSC testing the maximum discharge rate occurred during a high cluster load test (approximately 11000 watts). The approximate discharge rate was 11 amperes.

Specific CBRM outputs were also turned off during charging in order to allow the batteries to recharge at a higher rate. See Table 7.XI.

Battery cycling performance from the time of OWS solar wing deployment until the undock of the CSM was satisfactory. 166 cycles were accumulated prior to the first manned mission. 420 cycles were accumulated in the course of the first manned mission. The discharge and recharge modes of battery operation were as predicted for the lower DOD after DAY 25. (Nominal recharge fraction, battery temperatures versus voltage.)

The solar inertial depth of discharge range most commonly experienced during the period prior to the first manned mission was 19% to 50%. Figure 6.14.

The solar inertial DOD range experienced during the first manned mission was 25 to 32% prior to OWS solar array wing deployment. After wing deployment the solar inertial DOD range was 0 to 23%. Depths up to 54% were experienced during Z-LV-EREP maneuvers.

Battery performance remained uniformly acceptable during the storage period between the first and second manned missions. Continuous solar energy was available to power the vehicle for the initial four days of this storage period because of high beta angle conditions. The batteries were not cycled for this full sunlight period. The batteries resumed normal operation on DAY 44 and cycled at a DOD as high as 15% during the remainder of the storage period. Total accumulated cycles reached 1137.

The batteries had accumulated 2054 flight cycles at the time the second crew departed on DAY 135. The DOD range during the solar inertial orbits of the second manned mission was 14 to 24%. During Z-LV-EREP attitudes, the DODs ranged up to 50% during the EREP on DAY 113. See Figure 6.14 for average daily ATM DODs.

Capacity tests during the second manned mission were run on five different batteries to determine an acceptable limit to which the ATM batteries could be discharged. The selection of batteries to be tested was made with the following criteria: (1) The first battery tested (#7) had the lowest capacity during preinstallation tests and was one of the batteries with higher temperatures during the initial unmanned period. (2) The next two batteries tested (#10 and #18) had most telemetered parameters available on the ATM tape recorder for continuous data recovery. One was a "hot" battery and one was "cold" during the initial unmanned period. (3) The next two batteries tested (#5 and #8) gave another example of a hot and cold battery. Batteries 10 and 18 tests were repeated twice later in the second manned mission. CBRM #5 was retested and experienced a charger failure during its second test. Table 7.IX lists the capacity tests run during the mission. Capacity was determined by integrating the battery current over the total discharge period.

Prelaunch capacities of ATM batteries had been determined prior to installation for thermal vacuum test operations at JSC. Those CBRMs, which were modified during KSC operations, had their batteries tested at MSFC prior to return to KSC. However, these tests were run to a discharge level of one volt per cell. The inflight system automatically took the battery off line at 26.4 volts or 1.1 volts per cell. This would tend to indicate greater capacity during ground tests than inflight tests. Also, the flight tests were run only to "battery voltage talkback" (which occurred at 27.5 volts) in order not to auto disconnect the battery intentionally.

BATTERY	MISSION DAY	CAPACITY (AMP-HRS) Estimated to Auto-disconnect
7	93	12.1
10	102	12.4
18	102	13.1
5	104	12.1
8	104	12.5
10	105	12.2
18	105	12.9
10	118	11.7
18	119	12.4
10	122	11.6
5	122	11.4
10	195	13.0 (Tests run at low
18	195	13.0 discharge rate)
10	229	9.25
18	229	10.66

Note: An astronaut monitored each test and terminated battery discharge upon observing the battery voltage flag which indicated battery voltage of 27.5 volts. In order to estimate the total usable capacity, 1.1 Ampere-Hours was added to the calculated capacity. (1.1 Amp-Hrs was the estimated delta capacity to discharge the battery from 27.5 volts to 26.4 volts).

Table 7.IX Battery Capacity Tests

Comparison of battery end-of-discharge voltages proved to be a poor correlation to battery capacity. However, without running the batteries to auto disconnect the end-of-discharge voltages were the only means of predicting capacity. See Figure 7.51 for discharge profiles on some of the capacity tests.

The batteries continued to provide sufficient power during the unmanned period prior to the third manned mission. The ATM power system was unparalleled from the AM power system during this period, so that ATM power was used only to power ATM hardware. Total accumulated cycles reached 2853. The DOD for this period ranged from 9 to 14%.

ATM battery discharge/charge cycle accumulation at the time of final crew splashdown on DAY 271 was 4108 cycles. The range of DODs during the SI periods for the third manned mission was 0 to 24%. See Figure 6.14. DODs up to 41.3% were experienced for off-sun pointing during the third manned mission, with the maximum DOD reading on DAY 259.

Capacity discharges were performed on CBRMs 10 and 18 at the beginning of the third manned mission (DAY 195). However, these tests were run at a lower discharge rate than the other capacity tests which could not be directly compared to the previous inflight capacity checks. These tests were repeated on DAY 229.

During the final week of Skylab operations, the flight controllers on the ground performed the battery capacity tests listed in Table 7.X. All of these tests were run to battery auto disconnect to determine actual capacity. Previous tests run to "talkback" (27.5 volts) used a factor of 1.1 amp-hours from "talkback" to auto disconnect. As seen in Table 7.X, the 1.1 amp-hours was seen to be adequate except for CBRM 7.

Ground tests on the life tests CBRMs indicated a range of 1.1 to 4 amp-hours from "talkback" to auto disconnect. However, after 3800 cycles on the life test unit, this number decreased to about 1 amp-hour. The delta 1.1 Amp-Hrs was based on these tests.

A comparison was made of battery voltage versus amp-hours removed during discharge at similar currents. Comparison indicated small change in V-I characteristics over the mission at low DOD. There was a wider variation of voltage at end of discharge at higher DOD when compared from BOM to EOM.

Two types of anomalies impacted battery performance. One was the result of electronic failures (CBRM 3 and 5), and the other was the result of changes in battery characteristics from predicted.

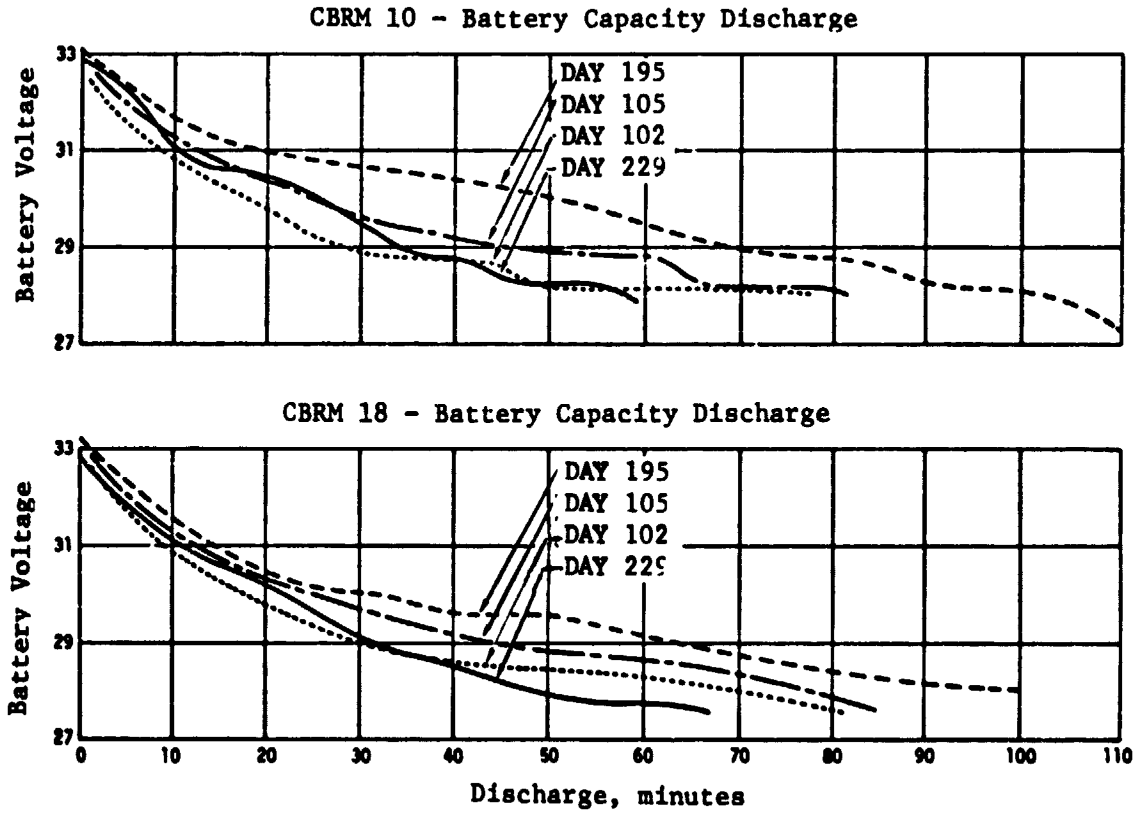

Figure 7.51 Comparison of Discharge Battery Voltage, During Capacity Test

Battery	Mission DAY	Capacity (Amp-Hrs) Estimated (To talkback = 27.5 volts) plus 1.1 AH estimated to auto-disconnect included	Capacity (Amp-Hrs) to A-D *
1	267	8.9	9.7
2	265	No Data Available.	10.9
4	268	11.1	11.4
6	270	8.8	9.5
7	269	7.3	7.2
8	267	8.6	8.9
9	267	9.9	11.5
10	265	8.3	11.9
11	268	9.4	10.0
12	268	10.1	11.1
13	265	No Data Available.	9.8
14	266	No Data Available.	11.2
15	270	11.2	11.6
16	269	8.0	8.7
17	269	No Data Available.	8.9
18	265	8.9	11.5
7	270	7.9	7.5
8	270	8.8	8.7
11	270	9.7	9.6
16	270	8.8	8.6
* AVERAGE - 10.25 AMP-HRS.			

Table 7.X End-of-Mission Battery Capacity Tests

The latter battery performance anomaly was a loss in usable battery capacity. This characteristic was first observed on DAY 17 when, during an EREP pass, several CBRMs were automatically disconnected as a result of low voltage. The measured capacity, which was expected to be at least 15 ampere hours, was approximately 8 ampere hours. Subsequent capacity checks on DAY 122 (11 A-H) and DAY 229 (10 A-H) indicate that the available capacity increased slightly after DAY 17 and remained relatively constant during the remainder of the mission. The capacity checks are shown in Figure 7.53. Although the capacity loss did not seriously affect the mission, it was an anomaly that was unexpected and unexplained.

The evaluation of the capacity loss requires the definition of two factors, memory and fading. Memory is a capacity loss which has been demonstrated to be recoverable. The memory variables are temperature and DOD. Fading is defined as a permanent loss in capacity which is essentially a form of accelerated aging.

The effects of memory are shown in Figure 7.53 by the recorded data from the Skylab simulation test performed at MSFC on relatively new cells. After degrading to approximately 10 ampere hours as a result of the simulation program, the capacity recovered to the expected level. The fact that the subsequent capacity of the simulation test battery did not remain within the expected range is attributed to fading.

The lack of capacity recovery indicated by the Skylab flight data shown in Figure 7.53 is attributed to fading. Likewise, the sharp drop in the life test battery capacity occurred at cycle 3800 and was also attributed to fading. In all three cases, Skylab flight life test and simulation, the fading occurred immediately after subjecting the batteries to the conditions which occurred during the first 15 days of the Skylab mission. These conditions, summarized in Figure 7.52, were:

> Battery temperatures were 25°C to 30°C for approximately 15 days on several batteries. On the remaining batteries, the temperature did not exceed 15°C.
>
> High depth of discharges 25% to 35%, occurred on all the batteries.
>
> Charging was often incomplete, i.e., less than 100%.
>
> Charge rates were much lower (5 to 8 amperes) than the normal 15 amperes.

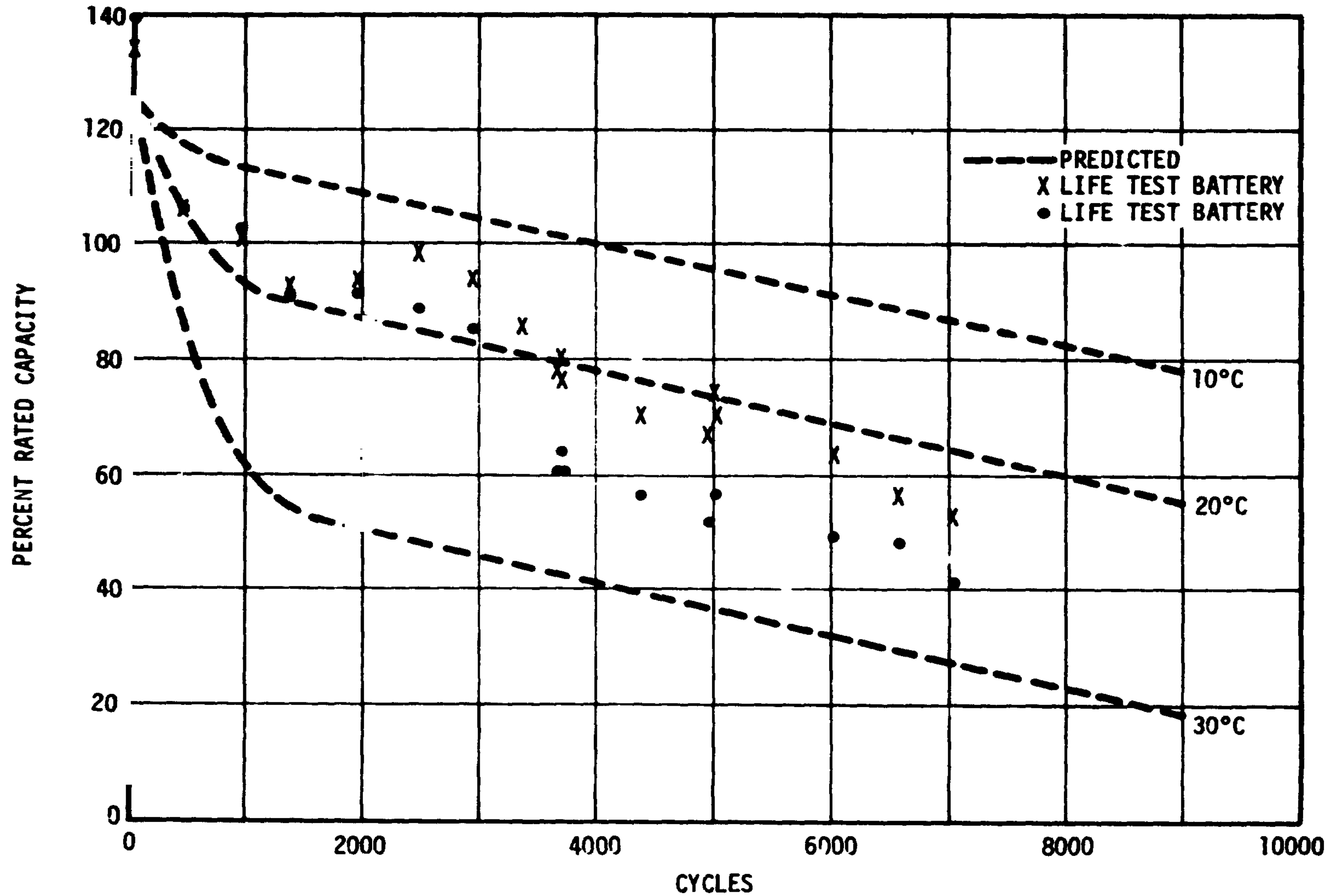

Figure 7.52 ATM Battery Capacity Degradation During Life Test

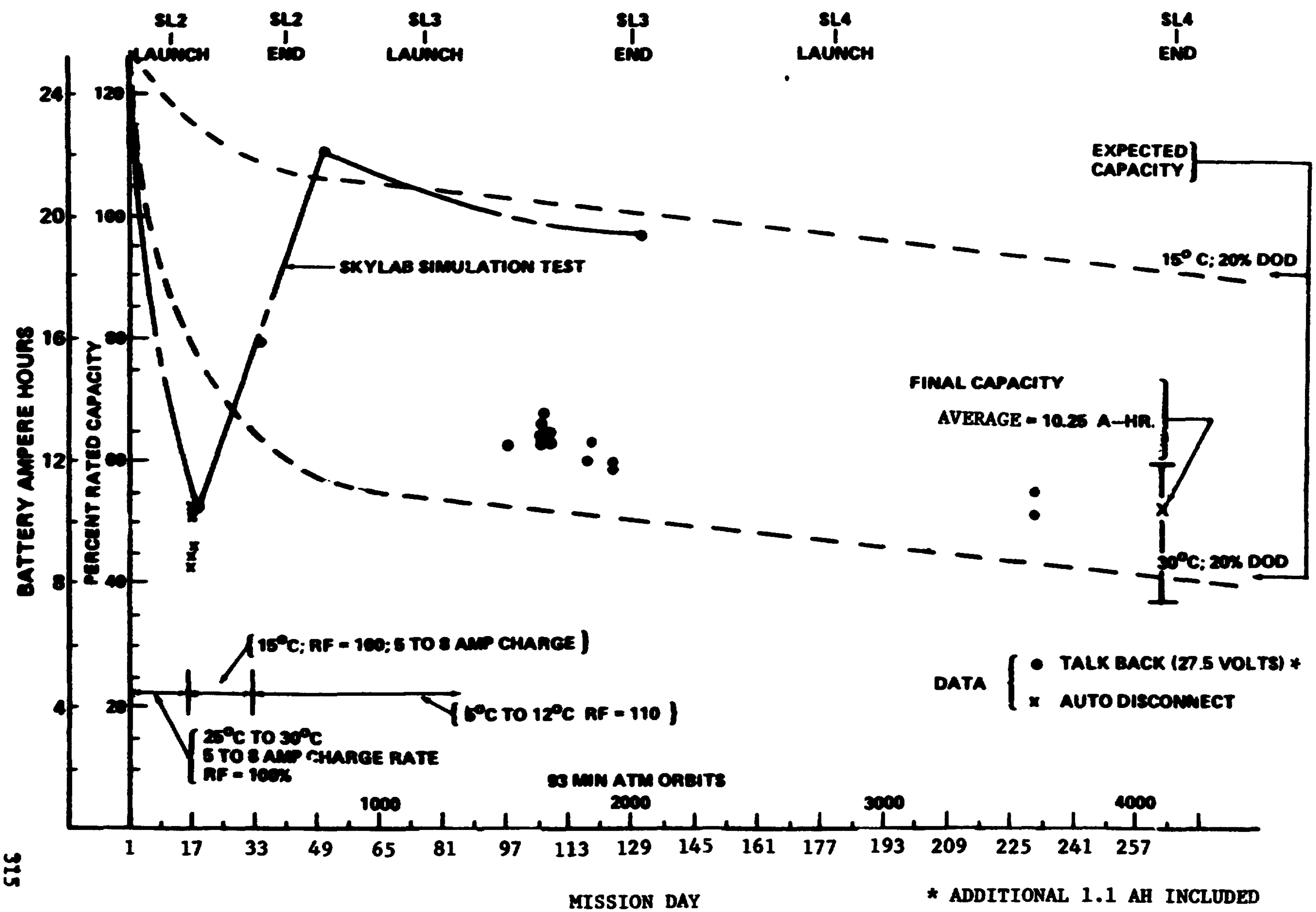

Figure 7.53 Battery Capacity Characteristics

Skylab batteries which demonstrated the greatest fading sustained 12 months of vehicle integration testing prior to launch such as trickle charge and open circuit stand.

Life test batteries which demonstrated the second greatest fading and accumulated 3800 simulated ATM cycles at the time the fading occurred.

The Skylab simulation test batteries which demonstrated the least amount of fading were new and unused batteries.

Fading is apparently a combination of two or more of the above factors. At present, it remains a matter of experimental investigation to determine what the relationships are in quantitative terms. This type of information will be of considerable importance in future long term space missions.

The other battery parameters, such as recharge fraction, watt hour efficiency, and third electrode controls, remained relatively constant throughout the mission. Life test data confirmed these observations. The recharge fraction remained approximately 110 percent at a 20 percent DOD at 10°C with a corresponding watt hour efficiency of 80 percent. Some of the pertinent factors are shown, which provides a band to indicate the range exhibited by all Skylab CBRMs. (Figure 7.54.)

A change in battery cyclic characteristics occurred on CBRM 9 whenever the discharge time during a cycle decreased below 20 minutes. This characteristic occurred at high beta angles. The change was caused by a high third electrode signal which remained above 200 mV when the charger was to be turned on. The high signal, however, inhibited the charger throughout the subsequent charge cycle. During the subsequent discharge cycle, the signal decayed below 200 mV and the charger was then turned on in the following sunlight period. In effect, this condition resulted in two battery discharges for one charge. Although the cycles were not normal, the battery was not being abused and could function indefinitely in this mode. Normal cyclic operation could be resumed when the discharge time again became greater than 20 minutes.

Effective performance of the batteries was adequate to supply the mission requirements in spite of the encountered anomalies. Battery capacity was adequate and supplied all the necessary mission demands when power management was imposed. There were no battery cell failures during the mission.

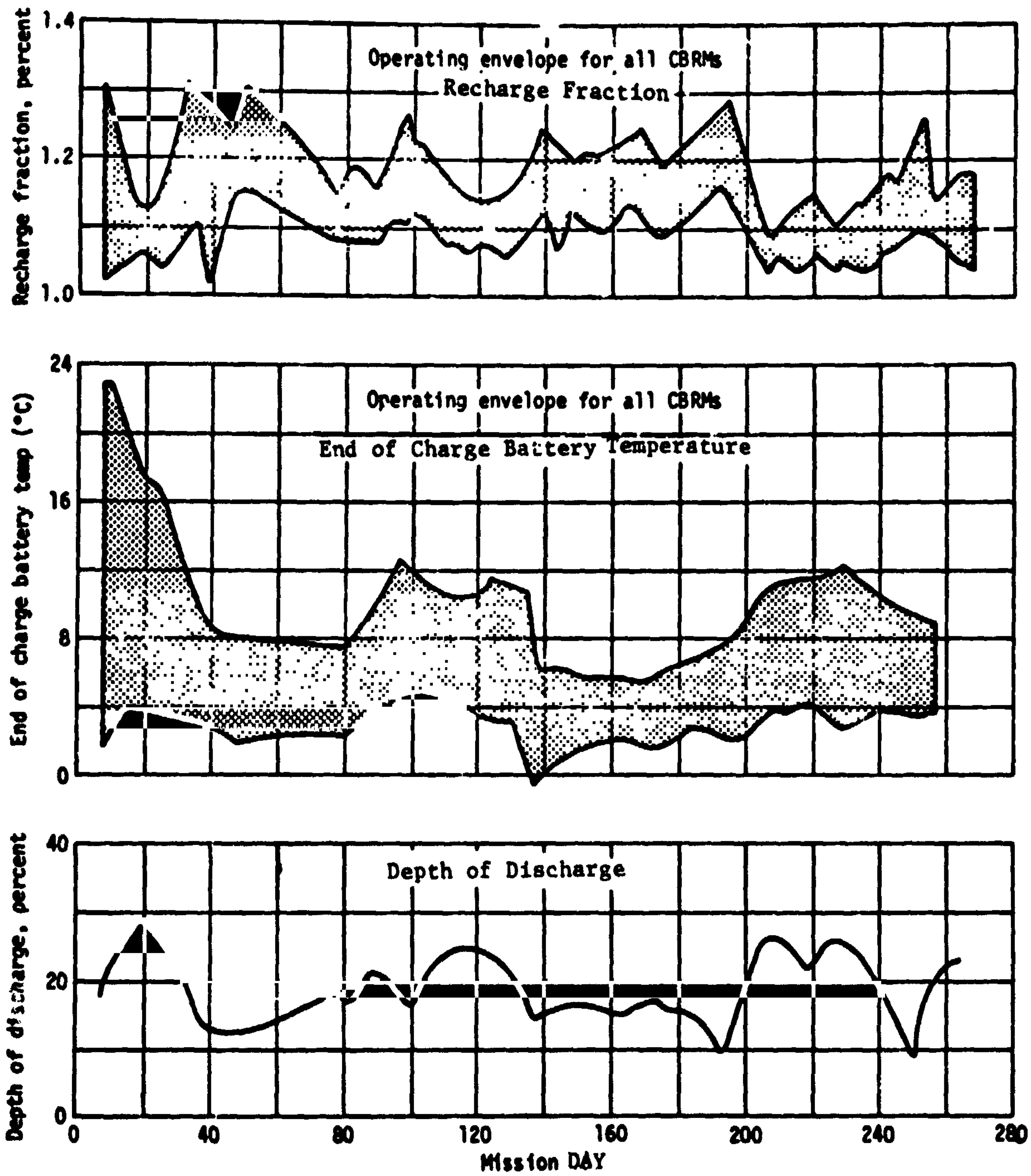

Figure 7.54 Operating Envelope for all CBRMs

(c) Voltage Regulator. The load regulator section of the CBRM converted a wide range of input voltage (25.5 to 80 volts dc) into a closely regulated output voltage. Input voltage was supplied by either the solar array or the batteries, whichever was higher. Output voltage was maintained between 27.1 volts dc at full load and 30.4 volts dc at no load, with the output current limited to 20.0 amperes maximum under output short-circuit conditions. The output voltage was modified by a remote sensing input signal to provide equal power and bus voltage. A block diagram of a CBRM regulator (one of eighteen) is shown in Figure 7.55.

During the first portion of the mission, the CBRM regulators were cycled off and on to allow the batteries to recharge sufficiently from the off nominal conditions existing prior to the first crew deploying the heat shield and the OWS array. Table 7.XI indicates which regulators were cycled on each mission day for power conservation. In addition, CBRM Regulator 15 was cycled at least 25 times in an attempt to unstick the SAS contactor for CBRM 15.

The only regulator failure noted during the mission was in CBRM 3. A failed component in the control circuit on DAY 17 caused the loss of CBRM 3 regulator output to the bus. Onboard status lights indicated the "regulator on" command was getting to the CBRM. All other functions of the CBRM worked.

One problem occurred on DAY 17 and repeated during the mission. Fluctuation of $\pm$ 1 ampere in the CBRM 4 regulator current was noted. The problem was believed to be caused by an open capacitor used in an internal RFI filter. The fluctuation did not migrate to the bus and therefore caused no problems.

During end of mission testing, the CBRM power sharing circuit was verified by switching both primary and secondary remote sensing circuits off and observing the anticipated 0.3 volt drop in bus voltage predicted from premission ground testing. Figure 7.56, ATM bus characteristics, shows this drop for 16 CBRMs, the number on line at the end of the mission.

Individual regulator voltages were not provided on telemetry but only as an onboard measurement. Therefore, individual regulator efficiencies could not be determined without crew observation of data which was not requested.

Average regulator efficiency was measured using the main bus voltage. Data from DAY 205 was used to calculate the efficiency. Based on 20% DOD, and the battery diode loss counted against the CBRM as a whole, the average regulator efficiency during the sunlight portion of an orbit was 92.4%. During the dark portion of an orbit the regulator efficiency was 89.3%.

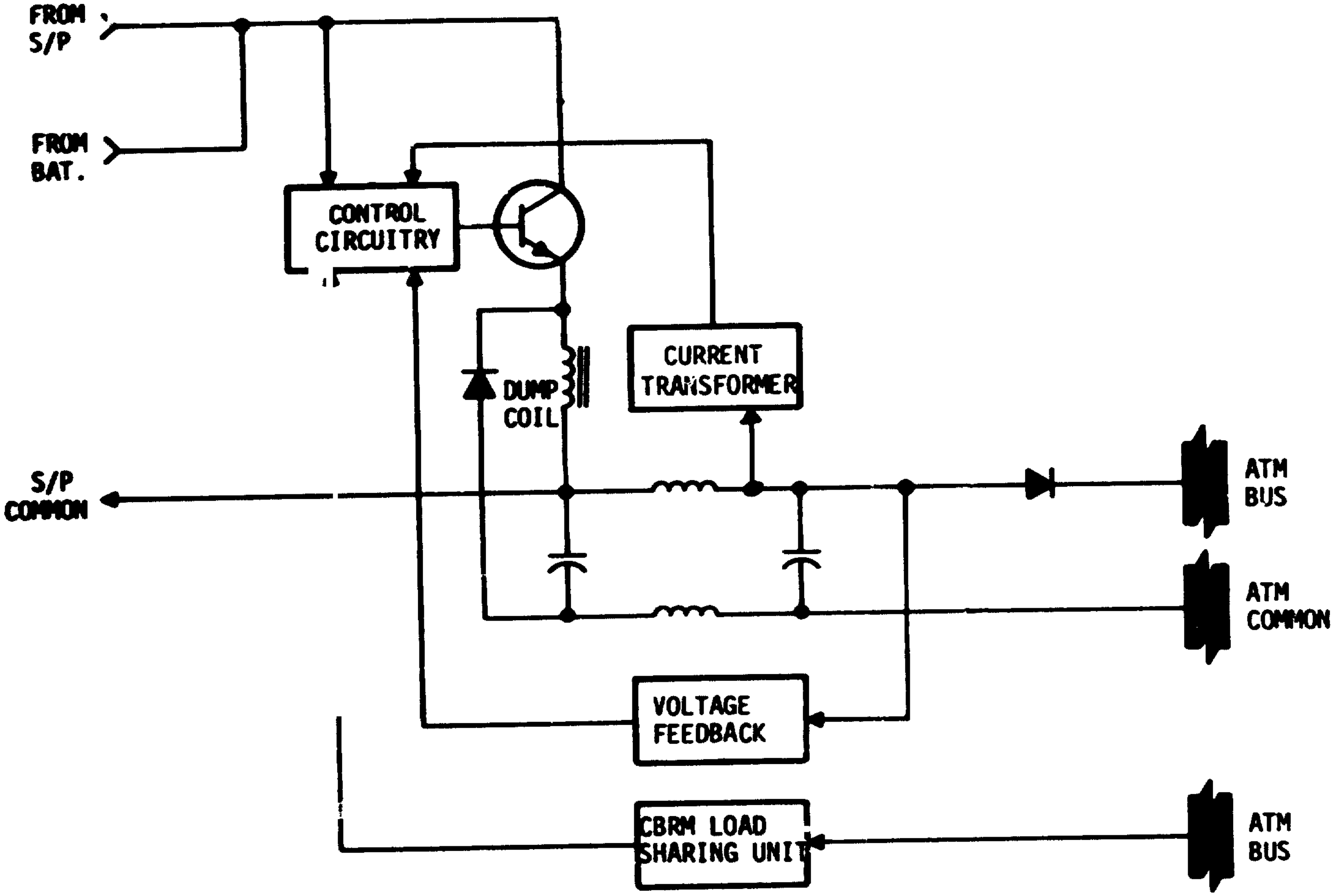

Figure 7.55 ATM Regulator Simplified Schematic

MISSION DAYS	3	4	5	6	7	8	9	10	11	12	13	17	
CBRM REGULATOR	NUMBER OF ON/OFF CYCLES												TOT
1													0
2													0
3						1		1			Reg Failed		2
4										1		1	2
5	1	8	3	9	7	9	7	11	11	2	8		76**
6	1	5	3	7	6	9	7	10	10	2	5	1	66**
7										1	2	1	4
8									1	1		1	3
9													0
10											1		1
11											1	1	2
12					1	1			1			1	4
13													0
14				1				1	2	2	2		8
15								2	2		*	*	4
16										1	3		4
17						2		1	2	2		1	8
18													0

**Note: CBRM 5 and 6 required extensive management because of canister shadowing in the off-nominal attitudes.

*Reg cycled 25 times in attempt to unstick the SAS contractor prior to DAY 37 EVA Fix.

Table 7.XI CBRM Regulator ON/OFF Cycling Matrix For Power Conservation (Pre OWS S/A Deploy)

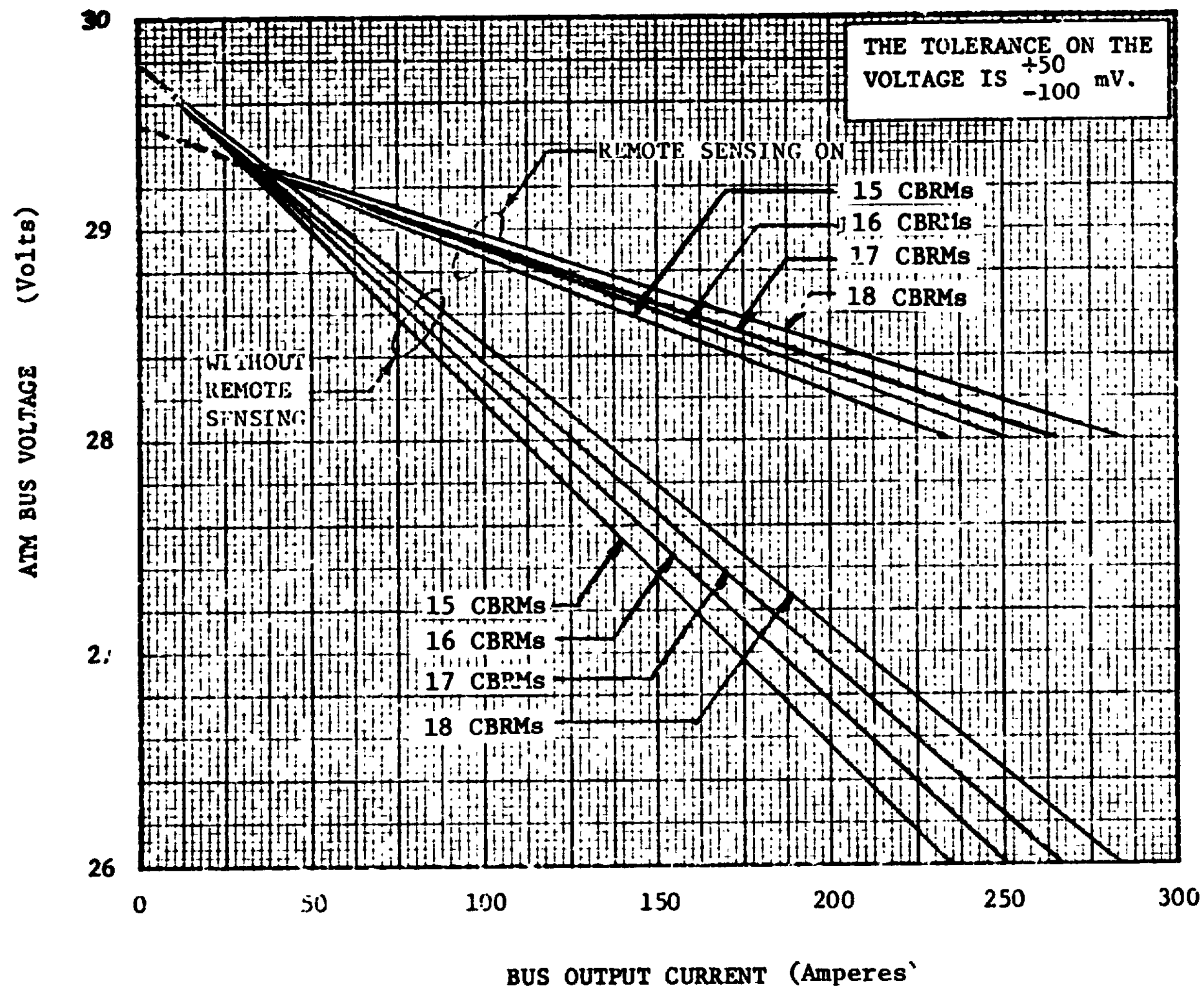

Figure 7.56 ATM Bus Characteristics (Two Buses)

The total CBRM efficiency, not including line losses from the solar array, was 78.1% based on an average CBRM load of 180 watts. On DAY 266, using data from CBRMs 2, 7, 10, and 18, the CBRM efficiency based on 235 watts per CBRM was 79%. This ndicated, as did premission data, that the efficiency increased as the load went up.

During the mission it was noted that the DOD of CBRM battery #11 was higher than anticipated compared to the other batteries. This was explained by the fact that the regulator characteristics of CBRM 11, in premission tests, showed that its regulator tended to provide slightly higher output power than the other CBRMs. Table 7.XII compares premission regulator currents from KSC test KT-1110 and mission regulator currents from DAY 241 for an evaluation of power sharing.

REG. CURRENT	KSC Test KT1110	Flight Data (DAY 241)
Average	7.035 AMPS	7.032 Amps
Lowest		
CBRM 9	6.805 AMPS	6.832 AMPS
CBRM 13	6.885 AMPS	6.822 AMPS
Highest		
CBRM 11	7.190 AMPS	7.330 AMPS
CBRM 15	7.170 AMPS	7.230 AMPS

Table 7.XII Power Sharing Comparison

(3) ATM Power Distribution and Control. The ATM was launched with only the main buses energized. During the unmanned activation on DAY 1, the command to turn on the ATM Power System CBRMs was sent automatically through the IU automatic sequencer at 17:50. This command was sent in case of anomalous EPS shutdown during the boost phase because the TM system was not yet activated. At 18:06 the IU automatic sequencer activated the TM buses which power the ATM telemetry system. Automatic activation of the ATM APCS was delayed until 19:07 with activation of the APCS buses. ATM experiment TCS activation was delayed until DAY 2 at 18:35. ATM/AM buses were paralleled early on DAY 1 at 19:27. The ATM transmitter was powered at DAY 1 at 22:34. On DAY 14 after crew arrival, the ATM C&D console was activated from 18:05 to 18:30.

On DAY 14, during initial experiment activation, an undetermined internal S054 experiment failure made ti impossible to turn off by conventional means, the Experiment S054 Main Power. Ground commands had successfully activated the S054 Main Power but subsequent ground commands (at 06:40) and later crew commands to deactivate were unsuccessful. The only known method to turn off S054 Main Power involved deactivation of the ATM experiment buses. It was decided to leave S054 Main Power on for the duration of the mission.

Feeder circuits were designed to carry 2500 watts in either direction and proved capable of carrying in excess of 3200 watts on DAY 17. Vehicle response to commands and telemetry data for system monitoring was good. One anomalous TM measurement, which sometimes read offscale high, was the current measurement for ATM Main Bus Two. This measurement had been intermittent during KSC testing.

Circuit protection devices and overall circuit control performance was normal with exceptions occurring after the start of the second manned mission.

The most serious distribution system anomaly occurred on DAY 83 when a 500 ampere current spike was observed on ATM Main Bus 2 for three seconds. The ATM TV Bus 2 voltage went to zero. After much ground analysis and testing, it was determined that a hard short from ATM TV Bus 2 to ground occurred in the power transfer distributor.

Power circuits from ATM Main Bus 2 to TV Bus 2 could not sustain the short. The location of the short and the extent of the damage could not be assessed. ATM TV Bus 1 was sufficient to provide TV Bus power for the remainder of the mission, although a work-around was provided for the third crew as a backup to TV Bus 1.

On DAY 85, the tenth day of the second manned mission, the ATM EVA lights were commanded ON from the C&D Panel, but the crew noticed them to be OFF during the EVA operation. The lights were re-enabled and operated normally during the remainder of the mission. The most probable cause was the issuance of an inadvertant disable command making the lights unable to respond to the "ON" command.

After the bus short occurred, many discrepancies accompanying ATM C&D panel control and monitoring of the power system occurred, which could possibly have been traced back to debris from the short. None of these discrepancies affected the ability of the power system to provide sufficient power. See Figure 7.57 for a description of the alert logic of the ATM power system. The alert and EPS controls section of the console are depicted in Figure 7.58.

On DAY 83 the crew turned the rotary switch on the ATM C&D panel to the CBRM 17 position to obtain readouts, and CBRM 17 regulator went off. A subsequent turn of the rotary switch to CBRM 16 resulted in the CBRM 16 regulator going off. The ground commanded both regulators back on and proper operation resumed. On DAY 89, during troubleshooting, CBRM 17 operated properly, but CBRM 16 regulator remained ON when the crew turned the regulator switch on the C&D panel to "OFF." When the "rotary switch cycle test" was performed on DAY 93 there was no abnormal regulator turnoff. However, the crew had not tried to switch CBRM 16 regulator OFF and no attempt was made from the ground to command it OFF.

On DAY 98 the crew reported C&D "battery charge" alert light "ON" and the flag was in the "barber pole" position in all CBRM positions. Subsequently, the flag went back to normal (gray) without any action being taken. The crew was unable to determine which battery caused the alert and flag indications by troubleshooting, however, batteries 3, 7, and 17 current, voltage and temperature measurements were erratic (low and off scale low) during crew troubleshooting.

On DAY 105, during battery capacity testing, the crew was unable to turn off CBRM 7 regulator from the C&D panel. No attempt was made to turn the regulator off by ground command and a capacity test on CBRM 10 was done instead.

On DAY 123 the crew reported the "Regulator Voltage" talkback flag on the ATM C&D console was "barberpole" during the day and "gray" during the night portion of the orbit, while the crew was monitoring CBRM 10. Other CBRMs were selected but the anomaly did not clear itself. Regulator voltages read within limits on the panel meter.

On DAY 144 after the issuance of several "Main Power Off" commands to the S055 experiment, the experiment remained powered up. This commanding was done from the ground during the unmanned period between

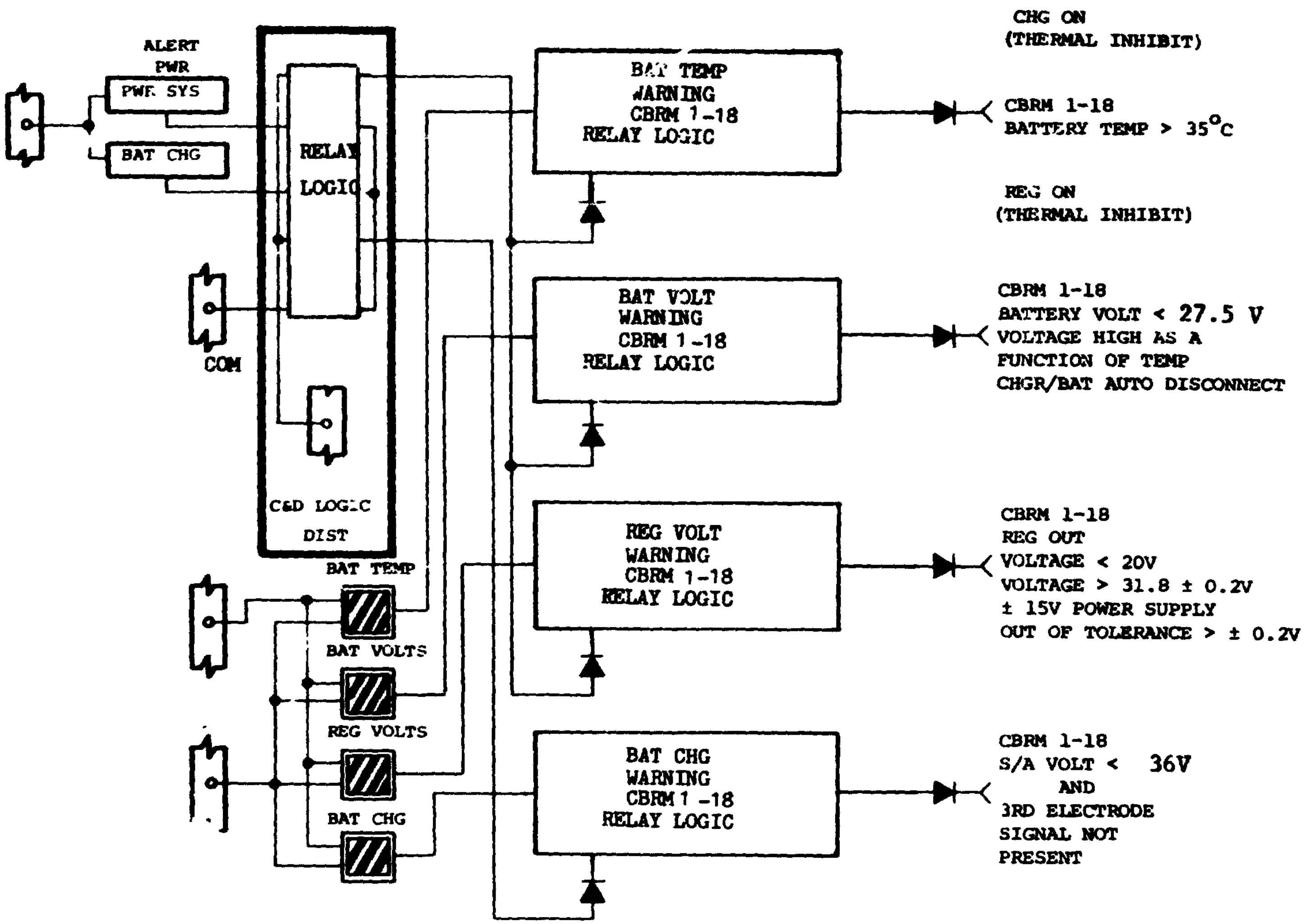

Figure 7.57 CBRM Warning and Alert Lights

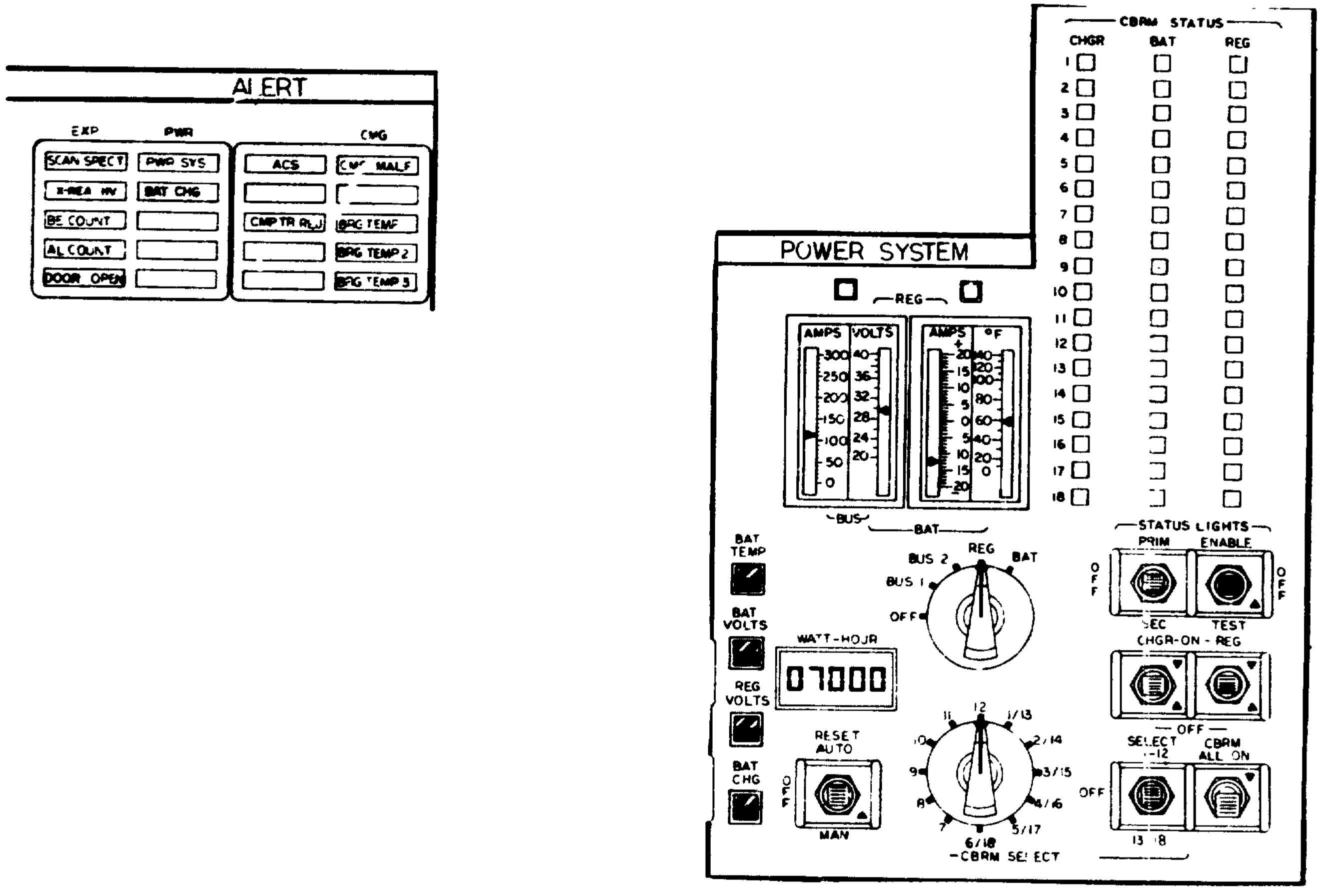

Figure 7.58 Power System Alert and Control Section of the ATM C&D Console

the second and third manned mission. During the third manned mission panel activation on DAY 187, the S055 experiment's C&D panel power switch was configured to secondary and no further onboard troubleshooting was attempted.

System activation by the third crew was normal with no problems occurring in the power distribution system.

The vehicle command system responded free of failure to all commanding, by both crew and ground. Monitoring of the ATM system via telemetry and crew response was efficient in enabling rapid resolution of anomalies.

On DAY 195 during capacity testing of CBRM 10, the crew had CBRM 10 selected on the ATM C&D panel. The crew executed "CBRM 10 Charger On" and CBRM 5 and 10 chargers came on. CBRM 5 charger was commanded off and CBRM 5 and 10 chargers went off. A test was performed where CBRM 11 was selected and the ground commanded CBRM 11 charger on. CBRM 11 charger was already on; however, CBRM 5 charger came on. The select switch was disabled and CBRMs 5, 10, and 18 were commanded from the ground and all commands worked properly. This test proved that the CBRM 5 charger on/off control relay failed closed. The effect of this failure was cross-talk between CBRM 5 charger commands (DCS or crew) and any CBRM charger selected on the C&D console. The select switch was therefore left in the "Off" position, thereby not selecting any CBRM.

After crew splashdown and prior to final vehicle power down a brief period of time was allotted for the conducting of many essential electrical network system closeout tests.

The tests and their results were as follows:

1) The ATM electrical system bus redundancy design was tested to check its EOM reliability. The procedure consisted of alternate powering down of each subsystem's redundant bus. Telemetry responses were monitored during this time frame to confirm that all subsystem loads remained active while the respective buses were cycled. All subsystems confirmed the reliability of the redundant bus arrangements except for the ATM TV system buses. The test showed that the secondary TV bus had been lost due to a short on the bus during DAY 83.

2) The primary ATM measuring bus operated without degradation throughout the entire Skylab program. The secondary measuring supply was activated to determine its capability at EOM. The secondary measuring supply was activated successfully with no noticeable degradation.

3) Testing of the primary H-alpha-2 door motor logic circuitry was conducted. The test would verify the operational status of the primary motor circuitry talkback and primary door motor. The procedure called for the inhibiting of both primary and secondary motor power and the re-enabling of the primary circuitry. Re-enabling of the primary circuitry failed to produce a door talkback indicating the loss of the primary drive circuitry. A possible cause could have been a short in the drive motor or associated circuitry resulting in a blown fuse.

4) The activation of the secondary auto playback timer in the auxiliary storage and playback system to dump tape-recorded telemetry was initiated to verify the backup timer unit. The secondary auto playback timer functioned normally as evidenced by the automatic commanding of the tape recorder to the record mode following approximately six minutes of data playback.

5) The S054 and the S055 command capabilities were investigated further. The test procedures served primarily as additional troubleshooting in an effort to determine the causes behind mission failures involving the inability of commanding each experiment's main power "Off". Ground commands were issued to turn off each experiment's main power and real time data was analyzed. Attempts to deactivate both experiments via main power "Off" ground commands were unsuccessful.

   Analysis of the S054 anomaly indicates the most probable cause is a failed power relay in the set position as both ground and earlier panel commands to deactivate were unsuccessful.

   Earlier requests for the crew to command the S055 experiment "Off" via the panel switch were rejected. Several attempts to deactivate via ground command were unsuccessful. Due to limited permissible troubleshooting approaches, only suppositions can be drawn. Possible causes might be a relay failure or open circuit in the command line to either of the two relays involved.

c. MDA The docking lights were successfully operated from the terminal phase of each manned mission maneuver and through docking.

The MDA interior lights functioned satisfactorily during the first manned mission.

The only MDA electrical subsystem anomaly, during the first manned mission, occurred on DAY 81 with the loss of the ATM C&D panel variable integral and number lighting. Tests performed did not positively isolate the failed component, however, the probable failure was indicated as being in the Pulse Width Modulation (PWM) inverter assembly.

A discrepancy occurred on DAY 20 when the MDA 70° primary wall heaters were commanded "ON". The heater groups 5 through 8 and 9 through 12 failed to energize. The crew determined, during the investigation, that MDA heater circuit breaker No. 2 was "Open". After verifying that excessive current or transients had not caused the circuit breaker to open, the circuit breaker was closed and the heaters commanded "On." The heaters operated satisfactorily; it was therefore concluded that the crew had inadvertently hit the circuit breaker, causing it to open.

An MDA internal lighting failure occurred during the second manned mission on DAY 99, with the loss of aft 2 and 4 lights. Troubleshooting indicated possible causes of failure could have been an intermittent failure of the light switch or relay. After successful reactivation, the Switch was taped in the "On" position and local control at the light was used for the remainder of the mission.

A loss of integral and numeric lighting on the C&D panel occurred on DAY 235. Numeric lighting was restored during troubleshooting which indicated that a possible short existed in the integral lighting system.

A comparison of power transfer voltage characteristics for power transferred from the AM transfer buses to the CSM is shown in Table 7.XIII. Prelaunch data obtained during KSC integrated testing is compared to flight data from DAY 130.

	KSC Data	Flight Data (DAY 130)
AM Transfer Bus 1 Voltage	28.3 Volts	28.5 Volts
AM Transfer Bus 2 Voltage	28.3 Volts	28.5 Volts
CM Main Bus A Voltage	26.5 Volts	26.6 Volts
CM Main Bus B Voltage	26.6 Volts	26.8 Volts
Calculated CSM Load (max)	2240 Watts	1978 Watts

Table 7.XIII Transfer Bus to CSM Power Transfer Comparison

d. Skylab Caution and Warning System. The C&W System operated nominally throughout the Skylab mission and performed all required mission functions. The system successfully monitored all seventy-six parameters and satisfactorily detected out-of-tolerance conditions. The system was operational for a total of 4011 hours. During this time, the system activated approximately 220 times.

(1) False Alarms. Out of the 76 parameters monitored, the only false alarms which activated the C&W System were associated with the fire sensor assemblies. These false fire alarms were attributed to the following factors:

(a) High Temperature. Three false alarms occurred on DAY 13 shortly after C&W System activation. The source of the alarm was FSA 639-1 which was located in the OWS center sleep compartment. These alarms were attributed to the excessively high ambient temperatures (approximately 145 degrees F) in this area. The FSA was qualified to an operating temperature of 100 degrees F. No additional alarms occurred after the SWS returned to normal operating temperatures following the deployment of the thermal parasol.

(b) High Radiation Levels. Four false alarms occurred during passes through the South Atlantic Anomaly. Dosimeter and proton spectrometer data indicated that at the time the alarms occurred peak radiation levels were encountered. On DAY 14 and 19, two alarms were activated by the No. 1 Cooling Module Fire Sensor (392-1). No additional alarms occurred following reduction in the sensor sensitivity setting from 35 counts/sec to 45 counts/sec. On DAY 232, and 248, two Experiment Compartment Fire Sensors (619-1 and 618-1) activated, respectively. The sensitivity of these sensors was not changed and the alarms did not reoccur.

(c) Sunlight. The following false alarms were caused by solar UV radiation entering the vehicle as direct sunlight or as reflected light, i.e., the earth's albedo.

During the first EVA on DAY 25, OWS cooling module FSA 392-2 activated with entry of sunlight through the opened EVA hatch. Since both OWS cooling module fire sensors were located in the compartment evacuated during EVA, the associated EVA procedures were revised to inhibit both OWS cooling module fire sensors.

Two erroneous fire alarms occurred on DAY 83 and were generated by the wardroom FSA 633-2. At the time of the alarm, the Skylab was passing through the South Atlantic Anomaly in a near Z-LV attitude with the wardroom window sunshade removed. In this configuration, the unprotected window was exposed to earth reflected UV radiation. Although the SAA radiation level also encountered at the time of the alarms was less than that observed at the time of the SL-2 alarms, i.e., approximately 0.1 vs. 0.19 Rad/Hr, the combination of both conditions was considered sufficient to have caused the alarm. No additional alarms occurred and no corrective action was considered necessary.

Two additional fire alarms occurred on DAY 114. The alarms were caused by ultraviolet radiation coming through the unfiltered OWS SAL window during the UV photography experiment S073/T025.

(2) During the Skylab mission, two C&W System related component failures occurred. They were:

(a) FSCP. During the SL-2 mission, one component failure was identified. Side 2 of Fire Sensor Control Panel 392, S/N 10, failed to respond to self-test and was successfully replaced with an inflight spare. The removed FSCP was retained onboard as an inflight spare for reinstallation in panel locations 530 or 619 in the OWS which used only side 1.

(b) Pump Delta P. During SUS Loop No. 1 activation on DAY 85, no C&W alarm was generated from the Pump Delta P sensing circuitry. This condition confirmed the loss of the EVA LCG-1 pump delta P sensing circuitry suspected to have failed during the SL-2 mission.

(3) During the Skylab missions, the C&W System in the AM/MDA U-2 vehicle and the C&W simulation in the Skylab Test Unit (STU) were maintained in a mission support mode. The Airlock U-2 Caution and Warning System configuration was identical to Airlock U-1. Special tests and operational modes were performed as required to support the resolution of problems or suspected problems on the SWS inflight. Data was plotted on all C&W System related parameters to monitor system performance and to observe parameter trends for out-of-tolerance or any erratic operation. This data primarily came from the STU/STDN facility at St. Louis. AM/MDA U-2 and STU were used to support significant mission problems occurring during the SL-2 mission in regard to fire sensor false alarms and OWS Bus 1 and 2 low alarm.

(a) Three false alarms occurred on DAY 13 shortly after activation of the C&W System. Fire sensor assembly 639-1 located in the OWS center sleep compartment was the source of the alarms. Testing was performed at the contractor STU facility on an FSA which failed at a temperature above the qualification temperature of 100 degrees F.

(b) An OWS Bus 1 and Bus 2 low alarm occurred when the associated CBs opened. The U-2 vehicle was utilized to perform a test to verify that both Bus 1 and Bus 2 low sense circuits functioned properly. The test to determine the possibility of a short circuit existing between the circuits due to a wiring incompatibility proved the C&W sense circuits performed properly and were not tied together.

8. Anomalies. The Skylab Mission Problem Tracking List was reviewed and Table 8.I is a summary of significant anomalies within the Electrical Power System. A list of all Action Reports assigned to or contributed to by the EPS Mission Support Group is included in Appendix 1.

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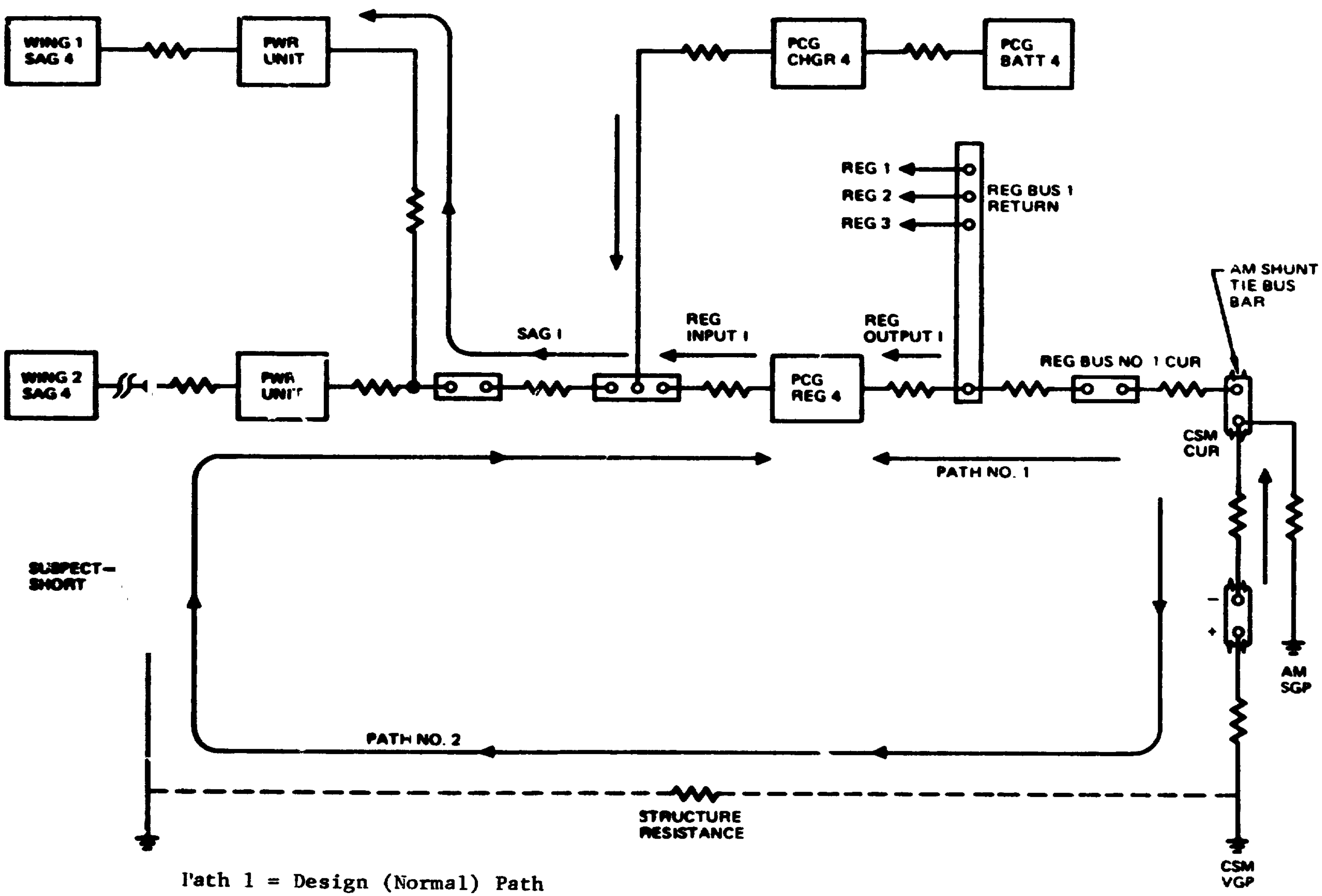
ITEM	TIME OF OCCURRENCE	MODE/CAUSE	MISSION EFFECT	CORRECTIVE ACTION/RESOLUTION
SOLAR ARRAY WING 2	LAUNCH + 593 SECONDS DAY 1	Removal of the entire wing. Mechanical failure of meteoroid shield, premature release of fairings and SII retrorocket exhaust plume impingement.	Reduce electrical power available to PCG's by 50%.	No repair possible. Perform rigorous power management for the entire mission to assure imposed loads do not significantly exceed power capability.
SOLAR ARRAY WING 1	LAUNCH + 593 SECONDS DAY 1	Failure to deploy automatically. Meteoroid shield debris restrained deployment.	Effective loss of AM EPS for mission support. ATM EPS required to supply all mission power requirements.	DAY 14 EVA crew activity which deployed the wing resulting in immediate power generation and supply to AM EPS batteries and loads. Load sharing by AM EPS was about 46% of total for the remaining mission.
SAG 4 AND REG BUS 1	DAY 26	Current measurement readouts off-normal. Structural return path through PCG/SAG 4 return input existed through damaged Wing 2 wiring (Figure 8.1).	No mission impact.	IR voltage drops in the return paths to PCG resulted in circulating current. Path 2 current was not included in reg. bus 1 reading. The same current flowed through SAG 4 shunt but opposing normal flow. Thus, SAG 4 reading was low by the Path 2 amount. This imposed use of averaging techniques for performance analysis.

Table 8.I Mission Anomaly Summary
AM/OWS



Path 1 = Design (Normal) Path
Path 2 = Structure (Anomalous) Path

Figure 8.1 SAG 4 Current Anomaly

ITEM	TIME OF OCCURRENCE	MODE/CAUSE	MISSION EFFECT	CORRECTIVE ACTION/RESOLUTION
CBRM 17	OBSERVED DAY 24 03:00 OCCURRED DAY 11	Low output/intermittent short to negative on S/A Panel 17. Removed when panel cooled during night portion of each orbit.	CBRM 17 delivered full power 10 minutes into each night cycle, zero power in the day.	Short disappeared DAY 137, 17:11, reappeared on DAY 151, 04:22 and disappeared for good on DAY 151, 23:12. Prior troubleshooting localized fault to one of the S/A Panel 17 modules.
BATTERIES 4, 6, 7, 8, 17, 15, 11, 12	DAY 12 03:20	CBRMs tripped off due to depleted batteries and the associated low voltage trip off. CAUSES: High temperature, low charge rate, battery aging (preflight), high DOD resulting from SL-1 thermal attitude (55°).	Loss of a percentage of battery capability greater than predicted.	Power management techniques were being evaluated by MSFC/JSC.
BATTERIES 7 and 8	DAY 13 02:30	(Same)	(Same)	(Same)

Table 8.I (Cont) Mission Anomaly Summary
ATM

ITEM	TIME OF OCCURRENCE	MODE/CAUSE	MISSION EFFECT	CORRECTIVE ACTION/RESOLUTION
BATTERIES 6, 7, 8, 16	DAY 17 22:13	Batt. auto disconnected during 50% DOD EREP pass (1st) regulators went off at sunrise.	(Same)	Power Management techniques and battery DOD constraints imposed on mission resulted in no further auto disconnects.
CBRM 15	DAY 12 03:20	CBRM offline. Solar Array contactor failed open when both regulator and battery tripped off line after battery had depleted.	Loss of 1/18 of ATM power.	During EVA on DAY 37, the crew tapped CBRM 15 in an attempt to release the solar wing input relay contactor. The attempt was successful. The battery went into recharge and the regulator was successfully turned on. The CBRM functioned properly for the remainder of the mission.
ATM SOLAR ARRAY POWER #13	DAY 15	Open Solar Cell Mod[illegible] 1 or 2 of th[illegible] modules on panel 8 & 13 opened causing a 10% and 5% degradation at peak power.	2% higher DOD on CBRM 13 than the average of other batteries (during EREP or other high DOD usage).	
CBRM 3	DAY 17 22:00	Offline regulator control circuitry failure.	Loss of 1/18 of ATM power.	The CBRM was turned off after repeated attempts, to bring CBRM 3 reg on line failed.

Table 8.I (Cont) Mission Anomaly Summary
ATM

ITEM	TIME OF OCCURRENCE	MODE/CAUSE	MISSION EFFECT	CORRECTIVE ACTION/RESOLUTION
CBRM 6	DAY 17 22:40	Could not be turned off. Attempt was made to manage the DOD on CBRM 6 during ZLV. By turning CBRM reg 6 off to allow battery to charge. The reg went off for one minute and then came back on without an "On" command. Three subsequent attempts in the next 5 minutes resulted in the reg going off line and immediately coming back on. CAUSE: Faulty transistor on reg circuit board.	None	Four attempts to command CBRM 6 reg off were made from the ground with no success. The decision was made to leave CBRM 6 on for the remainder of the mission. During post mission testing CBRM 6 battery was taken to auto disconnect and successfully recharged.
CBRM 4	DAY 17 02:06	Charger Off CBRM 4 Regulator was commanded off and charger 4 also went off.	None.	CBRM 4 "Reg Off" command was not issued for the remainder of the mission, until "Regulator Off" was commanded at EOM.

Table 8.I (Cont) Mission Anomaly Summary
ATM

ITEM	TIME OF OCCURRENCE	MODE/CAUSE	MISSION EFFECT	CORRECTIVE ACTION/RESOLUTION
ATM TV BUS 2	DAY 83 03:20	Hard Short. A 3 second 500 amp current spike between ATM Bus 7D21 and ATM TV Bus 2 was caused by a short in the power transfer distributor.	Loss of redundant TV Bus 2.	Several non-space environment (no vacuum) ground tests were run on prototype equipment (fuses, wires, and relays). Adjacent wires to the short did not burn, debris was scattered and relay contacts burned open. TV Bus 1 was used for the remainder of the mission. An end of mission test on TV Bus 2 indicated that it could not be powered.
CBRM 7 REGULATOR	DAY 105 15:30	Would not switch off. Crew attempted to initiate battery capacity test on CBRM 7 but regulator could not be switched off from C&D panel. PROBABLE CAUSE: Regulator relays stuck in "On" position.	None	Capacity test terminated. End of mission capacity tests on all CBRMs indicated ability to auto disconnect. No attempts were made on CBRM 7 (or 16) to switch them off by ground command until the regulator off command at the EOM power down sequence.

Table 8.I (Cont) Mission Anomaly Summary
ATM

ITEM	TIME OF OCCURRENCE	MODE/CAUSE	MISSION EFFECT	CORRECTIVE ACTION/RESOLUTION
CBRM 5	DAY 123 02:30	Charger Malfunction. During recharge of CBRM 5 battery after capacity test, the battery stopped charging prematurely. CAUSE: CBRM input shorted to the battery relay by a short in either one of the charger transistors or battery isolation diode.	Whenever the S/A panel contactors and the battery contactor were closed at the same time, the S/A panel was tied directly to the battery and charged the battery until the high voltage cutoff auto-disconnected the battery.	An interconnection of CBRM 5 regulator and CBRM 3 charger and battery was made available for the third manned mission but not implemented. CBRM 5 was used during EREP maneuvers and managed successfully from the ground.
CBRM 9	DAY 160 05:28	Battery Premature charge cutoff. CBRM 9 battery tripped off after 1.5 amp hrs had been returned of 2.6 amp hrs removed during the previous night. CAUSE: One of the auto disconnect parameters gave a transient output as a result of some intermittent or EMI glitch.	None.	CBRM 9 was turned back on during next night pass and continued to operate for the remainder of the mission.

Table 8.I (Cont) Mission Anomaly Summary
ATM

ITEM	TIME OF OCCURRENCE	MODE/CAUSE	MISSION EFFECT	CORRECTIVE ACTION/RESOLUTION
CBRM 9	DAY 189 19:34 DAY 245 03:06	Charged every other orbit at high beta angle. CBRM 9 battery recharge complete indication was not removed at start of orbit sunrise to allow battery to recharge. CAUSE: PPO_2 level in proximity of 3rd electrode in battery was high so that 2 discharge cycles were necessary to reset the recharge complete signal. The subsequent charge raised the PPO_2 to the same high level.	None	Reg 9 was commanded off for one discharge cycle which dissipated the overall PPO_2 level to a nominal value. Sufficient night duration (lower beta angle) was required for the discharge cycle to recombine the oxygen.
CBRM 5	DAY 195 22:55	Charger on/off control relay failed closed. During CBRM capacity test, crew selected CBRM 10 on C&D panel and executed CBRM 10 charger on command. Both char-	Extra control by ground.	Ground controlled CBRMs with no problem with the select switch on the C&D console in the "off" position. When control was required by the C&D panel, the last step was to turn charger 5 off. A test was performed to verify the proposed resolution.

Table 8.I (Cont) Mission Anomaly Summary
ATM

ITEM	TIME OF OCCURRENCE	MODE/CAUSE	MISSION EFFECT	CORRECTIVE ACTION/RESOLUTION
		ger 5 and 10 came on. CAUSE: CBRM 5 select relay for charger on/off command remained closed even when not selected.		
ATM SAS 13, 14, AND 15	DAY 209 23:28 (S/A 15) AND DAY 210 02:50 (S/A 14)	Panel Degraded. SAS Panel 15 voltage decreased from 40.6 volts to 44.0 volts with current unchanged at 13.4 amps. Battery current showed decrease. SAS Panel 14 showed similar changes the next day. SAS Panel 13 exhibited similar performance since early in the Skylab mission. CAUSE: 1 or 2 S/A panel modules, out of 20, open circuited.	Loss of one module in a source (panel) caused negligible effect. Loss of 2nd module resulted in a loss of 10 to 30 percent of that panel's power capability. No problem for normal loads.	Increased power management was required (off loading and OCV adjustment) during off-sun pointing maneuvers.

Table 8.I (Cont) Mission Anomaly Summary
ATM

ITEM	TIME OF OCCURRENCE	MODE/CAUSE	MISSION EFFECT	CORRECTIVE ACTION/RESOLUTION
ATM C&D PANEL LIGHTING	DAY 81	Loss of C&D panel integral and numeric lighting, using the bus 1 position of the switches. Both numeric and integral lighting switches were in the "VAR" position. The I/LCA 1 and AC 1 circuit breakers were cycled. with negative results Possible cause of lighting loss was a failure of the pulse width modulator (PWM) AC-1 inverter.	Loss of the variable lighting made it necessary to complete the mission using non-variable (fixed) lighting for the integral and numeric lights.	Additional troubleshooting was performed on DAY 88 with negative results. Tests performed did not positively isolate the failed component. Non-variable (fixed) integral and numeric lighting were used for remainder of the mission. See Figure 8.2.
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Table 8.I (Cont) Mission Anomaly Summary
MDA

ITEM	TIME OF OCCURRENCE	MODE/CAUSE	MISSION EFFECT	CORRECTIVE ACTION/RESOLUTION
MDA AFT LIGHTS	DAY 99	Failure of Multiple Docking Adapter aft lights 2 and 4. Troubleshooting indicated possible causes of failure could have been an intermittent aft 2 and 4 light switch located on the STS panel 207 or an intermittent relay located in the MDA power distributor.	Loss of aft 2 and 4 lights, prior to troubleshooting on DAY 110.	The light switch was deliberately taped as a reminder, to the crew not to operate it. To further preclude loss of the aft lights, lights 2 and 4 were controlled with switches located on the light assemblies instead of the switch on panel 207. To prevent operation of the light circuits during deactivation of SL-3 and activation of SL-4, the crew opened the "MDA light 2" circuit breaker on the STS panel 202. The circuit breaker was closed during activation of SL-4 and final deactivation.
ATM C&D PANEL LIGHTING	DAY 235	Loss of integral and numeric lighting on the ATM C&D panel. Troubleshooting restored the numeric lighting, indicating that a possible short exists in the integral lighting circuits.	Loss of integral lighting for the remainder of the mission.	The background integral lighting was not required for console operation; compartment lighting was adequate, therefore, no further troubleshooting nor corrective action was undertaken.

Table 8.I (Cont) Mission Anomaly Summary
MDA

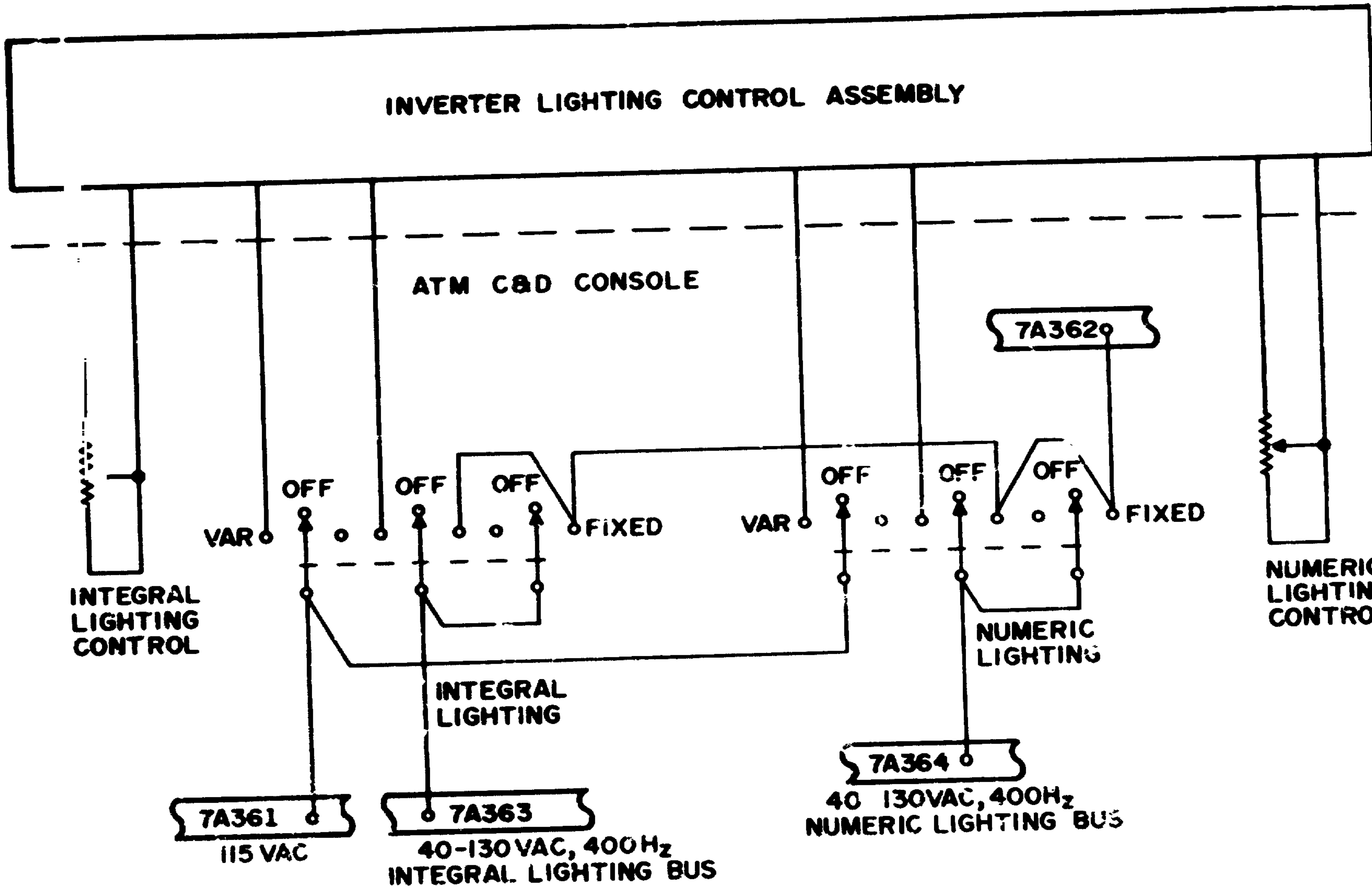

Figure 8.2 I-LCA and ATM C&D Console Power Interface

9. <u>Conclusions and Recommendations.</u>

a. Skylab Electrical Power System.

(1) Conclusions. The Skylab EPS performance was sufficient to support all mission objectives without significantly constraining mission planning and/or astronaut activities. The power systems performed satisfactorily in spite of the loss of one OWS solar array wing, and the stressing of ATM EPS hardware prior to deployment of the restrained OWS solar wing. The deliberate design feature of parallel operation for two independent sub-systems provided the flexibility which minimized the impact of the above conditions and other anomalies and thus proved to be mission essential.

Another contributor to mission success was the effective use of power management techniques. This tool permitted a relaxation in system battery DOD limits and allowed near real-time decisions for effective mission planning. This resulted in the approval of many data-take maneuver opportunities which might otherwise have been aborted.

The effectiveness of near real-time computer manipulations of data to give visibility for load management and updating of predicted performance was verified throughout the mission.

The fact that allowances had been made, in the launch configuration, for some hardware loss minimized the effects of losses during the mission. In fact actual losses were less than premission predictions. The required power capability for satisfying all end-of-mission essential loads of operational procedures was never lost.

Control and monitor of the EPS was mainly by ground controllers, thus freeing the crew for more cost effective duties. Occasionally, however, the crew was required to assist in EPS malfunction procedures, battery capacity verification, and AM Reg Bus Voc adjustment. All performance assessment was the responsibility of ground personnel based upon TM data and crew voice inputs.

The loss of the micrometeoroid shield and its thermal characteristics resulted in higher than predicted OWS temperatures; and this had the positive effect of eliminating the need for operating the OWS heaters. This reduction in predicted load helped to compensate for the power reduction resulting from the loss of one OWS solar array wing.

Additional instrumentation, for EPS engineering data, would have permitted more timely and accurate assessment of anomaly and degradation causes, which would have not only resulted in more effective Skylab monitoring, but would have yielded detailed information useful for future designs. The peak power tracking feature of the AM EPS resulted in efficient use of power from the single-wing solar array power source.

Open-Circuit standing and trickle charging for ATM flight batteries after installation may have resulted in the launch of batteries having degraded capacity of an undetected amount.

In spite of the above mentioned conditions the Skylab EPS operated successfully from SL-1 Countdown through SL-4 Splashdown.

(2) Recommendations. The following items have been identified during mission monitoring and data analyses and are recommended for EPS concepts, designs, and operation for future spacecraft:

Establish a working load management plan prior to launch.

Include sufficient instrumentation to permit effective engineering analyses of performance and anomalies.

Include paralleling feature if there is more than one power generation/conditioning system.

Use solar cell interconnector materials that more closely match the solar cell material and where possible eliminate the solder interface. This will be necessary for missions imposing large quantities of temperature cycles.

Include peak power tracking in future power control and conditioning designs.

Establish battery cell life data as a function of cyclic temperatures, DOD, and fading characteristics, premission.

Install fresh batteries, just prior to launch, and have their capacity verified.

Provide capability to monitor position of various switches on C&Ds by data word, which will eliminate need to use crew to verify switch position.

Include the capability to override automatic operations (such as meters and disconnect devices) to permit reset of drifting meters and to permit limited use of hardware beyond established limits under contingency conditions.

Avoid shadowing of power generation system and include articulation capability where practical.

b. Skylab Caution and Warning System. The following conclusions and recommendations are the results of a review of the C&W System design, the adequacy of the test program associated with this system, and the performance of the C&W System during the Skylab mission.

(1) Conclusions. The design and verification of the Skylab C&W System were proven to be effectual in that all required mission functions were performed satisfactorily. In addition to properly detecting all specified out-of-tolerance conditions, no false alarms occurred as the result of abnormal C&W System behavior or C&W System component malfunctions. The system was operational during all manned phases of the mission and successfully monitored all seventy-six preselected parameters relieving the crew to perform other assigned activities. The crew reported that the C&W System performed in an outstanding manner and that they were well pleased with all C&W System/crew interfaces; i.e., system control/inhibit switches, audio alarms, indicator lights, parameter categories, memory recall, and system reset capabilities. Out of the seventy-six parameters monitored, only the gas flow, $PPCO_2$ and CMG Sat parameters activated the C&W System an excessive number of times. The ATM CMG Sat. parameters activated frequently during periods of high crew activity and/or ATM rate gyro failures, while the $PPCO_2$ and gas flow alarms resulted from marginal sensing techniques utilized. Refinement in techniques to accurately measure $PPCO_2$ and gas flow are required to make parameters more meaningful.

(2) Recommendations. The following items were identified during system testing and/or mission support activities and are recommended to further improve the capabilities of the C&W System:

Provide the capability to monitor the inhibit switch positions associated with the various C&W parameters via a TM data word. Continual questioning of the crews was required to determine status of the inhibit switches.

Add TM parameter, with ground reset capability, to alert ground support personnel that a C&W alarm occurred and was reset while the vehicle was out of contact with STDN.

Improve techniques for monitoring $PPCO_2$ and gas flow to permit meaningful surveillance of these parameters.

Utilize high level (0-5 VDC) input signals in lieu of low level (0-20 mv) signals for better noise rejection characteristics.

Stabilize the C&W voltage parameters by balancing the TM output circuitry.

Impose stricter EMI requirements on component design to avoid late design changes as was experienced with the rapid delta P sensor.

Simplify wiring by incorporating circuitry presently contained in the High Level Audio Amplifier into the Caution and Warning Unit package.
Provide ground test capability of verifying sensors that are unavailable to monitor such as the mole sieve temperature sensors.
On future applications, add filter networks internal to the rapid delta P sensor and C&W signal conditioner packages.

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APPENDIX 1

HOSC ACTION REQUEST AND MISSION ACTION REQUEST LOG

HOSC AR #1	JSC MAR #	TITLE
1		SUBFRAME 1 RECORDING REQUIREMENTS
5		CHANGE IN STATUS OF CBRM 5 & 6
7		MOLE SIEVE BAKE OUT
9		ATTITUDE CONTROL MODE
13		CONTRACTOR SUPPORT
14		CSM STOWAGE FOR SL-2
16		ATM ASAP RECORDING REQMTS
18		CRITICAL LOADS MANNED PHASE
22		ORBITAL ATTITUDE FOR RENDEZVOUS
24		REVIEW OF MD-1 FLT PLAN
25		MOMENTUM MGMT @ X = -50°
29		AM COOLANT PUMP INVERTER STALL CURRENT
33		CRITICAL LOADS UNMANNED PHASE
34		ATTITUDE MANEUVER FOR SUS
36		THERMAL/ELECTRICAL MGMT PLAN
40		CANDIDATE STOWAGE ITEMS
43		REVIEW FLT PLAN MD 2, 4, 5
45		CONE ANGLE OF ATM SAS
47		MIN DATA WHEN COMPUTER DOWN
49		COMMAND PROCEDURES
	SWS1	DELTA-P DELTA-T SENSOR CDDT/FRT-INFO
	CM9	CSM PWR REQ (INFO)
	EX21R	PWR PROFILES FOR MED. SUPPORT EQUIP.
	CM33	XFR PWR ATM TO CSM SUPPORT EQUIP.
	Z087	OWS RENDEZVOUS PROFILE
	SWS92	ATM PWR CAPABILITY
	SWS94	LOOSE WIRES/PHOTOS/DWGS
	SWS131	TEST FOR SAS
	AX130	ATM EXP PWR LOADS
	Z0168	LIGHTING REDUCTIONS PERMISSIBLE
	SWS174	FLIGHT PLAN
	SWS201	SWITCH PCG CHG TO BYPASS
	SWS206	ZLV-R CAP
	SWS223	AM TAPE RECORDER USAGE
	Z0235	SWITCH PCGs 3 & 5 TO ON
	SWS268	ATM SAS TEMP LOWER LIMIT
	SWS277	ATTITUDE PREDICTION
	SWS311	PCG CONFIG. PRIOR TO SAS DEPLOY
	SWS350	PROPOSED C&W POWER UP PROCEDURE
	Z0288	SAS DEPLOY CRITERIA
	SWS376	CBRM MANAGEMENT

HOSC AR #	JSC MAR #	TITLE
	SWS428	EVA AUTO DOOR SWITCH
	SWS547	INPUT TO SUMMARY FLIGHT PLAN
	AX568	REDUCTION IN PWR FOR ATM EXP
145	SWS579	REQUESTED CHANGE TO C&W PWR UP
	Z0566	OWS PWR PROFILE W/SAS DEPLOYED
57	SWS380	20° ROLL AFTER SOFT DOCK
56	SWS372	EPS POWER NOTE 1
54	------	ATM CBRM #15 OFF
58	------	RADIAL DOCKING
---	Z0358	SMALL BATTERIES
65	CX175	COORD OF DATA TO RESPOND TO CX-175
HMAR-1	SWS414	DEACTIVATE ILCA HEATERS
67	SWS415	CBRM 15 TURN ON
	SWS416	FIRE ALARM SENSORS
	SWS428	EVA AUTO DOOR SWITCH
	SWS415	CBRM #15 RECOVERY PROCEDURE
	SWS414	POWER REDUCTION ITEMS TO LOWER ATM BATTERY TEMPERATURES & CONSERVE POWER
HMAR-11		CBRM #15 INFO
HMAR-6		SEC CONDENSATE DUMP HTR (INSTR. C&D CONVERTER CB)
74		UNDEPLOYED SAS ASSESSMENT
69		CBRM MISSION RULE DOD
76		CAPABILITY & LOAD PROFILE CURVE
77		OWS HEAT EXCHANGER FIRE ALARM
	SWS437	CBRM #15 RECOVER PROCEDURE
78		20 AMP SPIKE ON AM 1 BUS
90		PWR CAPABILITY CALCULATIONS
101		SEC CONDENSATE HEATER STATUS
103		DEFINITION OF LOAD PROFILE FOR SUMMARY FLT PLAN
115		MD-7 EREP GEOMETRY
124		ATM CBRM AUTO DISCONNECT
128		CBRM #15 RECOVERY PROCEDURE
127		PWR MGMT LOADS FOR EACH MD
130		ZLV GROUNDRULES
131		CBRM #3 TROUBLESHOOTING PROCEDURE
132		MD 7 LOADS
133		AH REMOVED FROM ATM BAT (EREP-1)
134		AM SEC COOLANT LOOP INV CB OPEN
156		ADDITION TO CONTAMINATION MISSION RULES
148	SWS590	GROUNDRULES
	SWS588	STAR TRACKER FLAG
142		S054 MAIN POWER TURNOFF
	SWS623	ILCA TEMPS

HOSC AR #	JSC MAR #	TITLE
	SWS631	CBRM BATTERY STATUS
	EX629	MDA WALL TEMP
178		MDA WALL HEATER
164	SWS613	HSS WMC OUTLET OVERLOAD
	SWS645	ILCA OP MODES
	SWS658	TACS FIRING
	SWS636	EPS PWR MGMT - HTRS
	SWS670	POWER DOWN CANDIDATES
191		EREP MANEUVERS FOR BETA $> 50^{\circ}$
188-E5		EREP PIE CHART
	EX656	RECONSIDER EREP PASS LOCATION
149	SWS591	EMERGENCY CREW MGMT OF ATM EPS
	SWS692	MD-12 LOAD PROFILE
168		OWS BUS 1 & 2 C&W
	SWS708	THERMAL SOAK ATTITUDE FOR SAS WING
	SWS707	BREADBOARD CBRM TEST
	SWS718	DOY 157 PANACEA
205		TEST FOR PWR XFER TO CSM
197	Z0694	ATM EPS OVERLOAD
	AX634	S054 DOOR FAILURE
	SWS719	WMC H20 HTR CIRCUIT
184		WASTE TANK VENTS
203		SAS EVA ADDED PROCEDURES W/SUPPLEMENTS
	SWS737	CBRM 17
	SWS738	PCG CONFIG. FOR WING DEPLOY
211		FIRE SENSITIVITY ADJ
212		C&W PARAMETER INHIBIT FOR EVA
213	SWS742	OFFLOAD FOR EPS MGT
226		S054 MAIN POWER
235		PCG REGULATOR BALANCING
238		AM PCG REG ADJUST POTS
237		EREP ZLV MANEUVERS
239		DATA REQ'D TO TRACK SYS STATUS WHEN NO R/T DATA
175		ATM 2 WING ATTACH TO MDA PORT
240		PWR XFER TO CSM
	Z0830	BATT CHG LITE RESET
	Z0840	USE OF EVA HDW FOR ADD HEAT LOAD ON SUS
	SWS845	EPS EVAL OF EREP PASSES (DAILY)
249	AX781	S054 DOOR
255		BACK TO BACK EREP PASSES
54R1	SWS870	EVA REPAIR OF CBRM #15
160		SL-2 RETURN/SL-3 LAUNCH STOWAGE
263		CBRM #6 FAILS TO TURN OFF
271		SL-2 CLOSEOUT

HOSC AR #	JSC MAR #	TITLE
268	SWS901	MDA WALL HTR 70° C/B
275		FSCP 392
269	SWS903	AM EPS/C&W ONBOARD STATUS
	SWS2154	ATM/AM BATTERY CAP TEST
284		WARDROOM WINDOW (USE OF HEATER)
287		UNATTENDED OPS - GND STA REQ.
289		S149 ATTACHED TO ATM SUNSHIELD (S/A SHADOW)
281		S055 DOOR DISCREPANCY
	AX906	S055 DOORS OPS ON 2 MOTORS
331		TROUBLESHOOTING PROCEDURE
	AX1014	S056 DOOR
356		
	AX1070	S054 LOGIC RESET
	AX1054	X-RAY ACTIVITY HISTORY PLOTTER
	AX1078	S055 DOOR PROBLEMS
375	AX1088	MGMT OF SYSTEM DURING UNMANNED
376		WH METER
377		SW SEL CMD DISCREPANCY
357	SWS1060	OWS SAG 4 CURRENT
	SWS983	FIRE SENSORS VS SUNLIGHT
312	SWS969	AM REG BUS OCV SETTING
270	SWS898	AM REG OCV SETTINGS
	Z0878	MD 13 FLT PLAN COMMENTS
247	Z0827	OWS S/A SWITCHING (PCG)
246	Z0826	FMR 6-381
392		T027/S073
	EX1095	PWR CONSTRAINTS - SL-3 - EREP PASSES
391		OWS BUS 1 PWR DOWN
	SWS1117	CBRM #3 SHUTDOWN
	SWS1118	CBRM #3 - POSSIBLE H2 BUILDUP
400		REVIEW FMR FOR SL-3
413		RSS TROUBLESHOOTING TECHNIQUES
	SWS1144	JOP 13 THERMAL ANALYSIS
437		OPEN SOLAR ARRAY TO CBRM #13
434		REVIEW OF SL-4 MRD
	AX1170	S054 READY/OPERATE LIGHT PROCEDURE
	AX1173	ATM APERTURE DOOR MALF PROCEDURE
	AX1176	ATM BB12 OPERATION
443R1		FMR CHANGES
	SWS1222R1	EREP PASS PWR ASSESSMENT
473		AUTOSCAN ASSESSMENT
425R6		MANNED MGMT CRITERIA
	SWS1228	ATM BAT CAP TEST DATA CURVES
485		INVALID DATA ASSESSMENT

HOSC AR #	JSC MAR #	TITLE
480		SL INFLIGHT PROBLEM REPORT
	SWS1154	CBRM 17 INFLIGHT TEST
	SWS1156	BAT CAPACITY TEST
496		MOLE SIEVE B, FAN 2
	SWS1261	ATM MAG LATCH RELAY
501		SL-4 STOWAGE
505		CBRM #15 C&D
	SWS1292	ILCA ANOMALY
509		ATM C&D CONFIGURATION
531		POTENTIAL RESCUE PLANNING
527		REVIEW AUTOSCAN EVENTS SUMMARY PROGRAM
	SWS1457	ID OF PWR XFER DISTR. FUNCTIONS
563		S052 LIGHT ANOMALY
554		S052 DOOR FALSE OPEN INDICATION
	Z01447	SWS CONFIG FOR RADIAL DOCK
	SWS1458	MECH DWGS OF 702A1 DISTR
	AX1459	TV MALF PROCEDURE
	AX1437	REV 6 MANNED MGMT CRITERIA
	1216	CBRM BAT CAPACITY VERIF
	1247	CBRM #4 FUNNY DOY 150
	1263	CBRM #4 CONTROL
	1390	S055 DOOR MALF.
	1468	SL-R RADIAL DOCKING
	1435	CBRM 17 FUNNY
	1436	ILCA PROCEDURE
	1456	S055 DOOR MOTOR OPERATION
569		TROUBLESHOOTING LIST
570		
571		S056 DOOR FAILED TO OPEN
574	SWS1478	CBRM 16 & 17 TROUBLESHOOTING PROC TO E[illegible]IL
575		TROUBLESHOOT TV BUS TWO
496		INCONCLUSIVE DATA - MOLE SIEVE
	1479	SL RESCUE POST INSERTION TIMELINE
555		QUESTION FOR CREW ON CBRM 16 & 17 ANOMALY
579		GND VS ONBOARD MOLE SIEVE TEMP READ
	1494	S056 DOOR OPERATION
581		SL-4 STOWAGE LIST
	1480	MOLE SIEVE TROUBLESHOOTING PROCEDURE
587		WCIU PLUG
588		ATM EVA LIGHTING OFF
593		OPS SYS W/O AM COOLANT LOOP
594		SYSTEMS STATUS

HOSC AR #	JSC MAR #	TITLE
595		CBRM 16, 17 TROUBLESHOOTING
522-7-8		EREP #7 & #8
600		MDAC-W WEEKLY SUBSYSTEMS REVIEW
	1543R1	CBRM ROTARY SWITCH CYCLE
613R1		CMG GIMBAL MEAS ERROR
625		MANNED MGMT CRITERIA
	1595	ED25 MANEUVER (JOP 13)
622	1581	ILCA PROCEDURE
629		FINE ADJUST POT ON PCG 6 & 7
630		CONTINGENCY NOTE #17
455		POWER DOWN CANDIDATES FOR ZLV-E
	AX1652	S082A DOOR OPS
	SWS1655	BAT CHG LIGHT ON & BP ON C&D
	SWS1385	TV 2 BUS ANOMALY
640		DOOR RAMP REMOVAL
	AX1670	DOOR RAMP REMOVAL
	SWS1673	SWS EQUIP DUTY CYCLE
641	SWS1695	ATM BATTERY TESTING
540-25		MDA LIGHTS/ATM C&D X-RAY & RNBM QUESTIONS
641	SWS1695	BATTERY TEST
	SWS1721	ATM C&D/ILCA
647		RATE GYRO 6-PACK OFF LOADING
660		MDA LIGHTS (AFT) TROUBLESHOOTING PROCEDURE
	SWS1728	HK70Y CBRM CAP TEST
	SWS1730	HK70Z PCG CAP TEST
663		S052 DOOR PROBLEM DURING EVA
665		EPS OPS W/BOTH COOLANT LOOPS INACTIVE
668		6-PACK SFP
672		3030A1 PCG BATTERY VER 30/238
	CSM1689	DISABLED CSM ELECTRICAL CLOSEOUT
	SWS1746	6-PACK SFP
676		SHORT M518 OPS PROPOSAL
675		CBRM 7
	SWS1760	SEC COOLANT LOOP
	Z01762	MANNED MGMT CRITERIA, SL-3
682	SWS1815	PWR MGMT COOLANT LOOP
	AX1767	JOP 13
	SWS1749	6-PACK
	1762R1	MANNED MGMT CRITERIA
	SWS1673R2	SWS EQUIP. DUTY CYCLE
691		HURRICANE MANEUVER
	SWS1812	CBRM BATTERY LIMITATIONS
	SWS1813	S052 DOOR ANOMALY
694		REVISE MGMT CRITERIA - CBRM DOD

HOSC AR #	JSC MAR #	TITLE
697		SYSTEM STATUS
700		C&W ALARM
	Z01844	REV 4 SL-3 MGMT CRITERIA
709	Z01855	SL-3 TROUBLESHOOTING CANDIDATES
708		EREP PWR UP/DN PROCEDURE
711		OWS LL MUX B INTERMITTENT OPS
715		REVIEW OF DOY 247/0730 DATA FOR "THUMP"
716		S/L #3 DEACTIVATION LIST
	SWS1878	ATM BATT RECORD ASSESSMENT
	Z01887	TROUBLESHOOTING PROCEDURE
725		XUV AUX TIMER INSTALLATION PROCEDURE
	SWS1887	TROUBLESHOOTING - R2- CBRM 4, DOY 145 - PROC.
	SWS1917	TV BUS ALTERNATE
729		H-ALPHA-2 DOOR ANOMALY
730		PANACEA/SEPSA DOD PREDICTIONS
	SWS1923	ATM BATT PRELAUNCH HANDLING
	AX1931	H-ALPHA-2 DOOR MALFUNCTION
738		BATT CAP VERIFICATION TEST
	Z01949	MANEUVERS FOR S201 EVA OPERATION
739		ANOMALOUS MEASUREMENT UPDATE
743		S082A DOOR
745		CONTINGENCY PWR DWN PROCEDURE
751		CBRM 5
749		SL-4 TEMP MEASURING DEVICES
747		6-PAK UNMANNED CONFIG ENVIRONMENT
760		EVENT STATUS FOR Y3 RGP NOISE
	Z01993	CDR/PLT COMM DURING M509 T020 RUN-SUITED
	AX1999R2	ATM TV BUS CYCLING
	Z02002	MANNED MGMT CRITERIA
	AX2005	S056 FILM XPORT HANGUPS
	AX1964	S082A DOOR INSPECTION DURING EVA-3
	SWS1972	CBRM #5 BAT TEMP
	AX1979	ATM EXP DOOR REMOVAL DURING EVA
759	AX1994	RATE GYRO 6-PACK
763	SWS1998	6-PACK GYRO ENVIRONMENT FOR UNMANNED
736		ADDITIONAL TOOLS FOR SL-4
754		CBRM #5 TAG UP
	SWS2017	PCG CAPACITY CURVES
775		REG TB VOLT ON C&D - REG 1-12
774		POST SL-3 UNMANNED CRITERIA
	AX1977R2	REFRIGERATION J-5
	SWS2024	ADDITIONAL LOSS OF COOL-DUTY CYCLES
777		JOP 13
	SWS2028	PCG MGMT FOR NO COOLING

HOSC AR #	JSC MAR #	TITLE
781		JOP 13 DOY 263
782		JOP 13 DOY 264
	AX2044	WLC FRAME COUNTER
	AX2042	ATM TV MONITOR/MGMT/TROUBLESHOOTING PROC
	Z02067-1	SL-4 UNMANNED S/C EXPERIMENT
	SWS2062	EVALUATION OF J5 DISCONNECT PROC
	AX2054	S082B TIMER INSTALLATION
	SWS2092	J5 DISCONNECT VERIFICATION
	AX2090	H-ALPHA-2 DOOR ANOMALY
803	AX2097	TV MON 1 TROUBLESHOOTING
805		OCV ADJ POT-STICK-ON LABELS
806		GURGLING SOUND
810		ATM TV MONITOR REPLACEMENT: SL-4
816		REMOVAL OF KICKPLATE TO PERMIT ADDITION OF TIMER
817		UNMANNED GROUND SYS MGMT
818		KOHOUTEK MGMT CRITERIA
825		SL-4 ACT/DEACT CHECKLIST
822		KOHOUTEK MRD ADDITION
834		JSC/TV
	SWS2139	PORTABLE TV MONITOR
	SWS2130	R/T DATA XFER TO MSFC SL-4
831		SL-4 PROBLEM INVESTIGATION STUDY
835		R/T DATA LOSS CONTINGENCY PLAN
840	AX2142	H-ALPHA-2 DOOR (PRI) OPERATION
838		FLT MISSION RULES
829		SL-4 DEACTIVATION
832		AM & ATM BAT TEST DURING SL-4
	Z02150	SUBFRAME 4 DATA
846		ATM TV MONITOR
	Z02146	CYCLING ATM EXP BUS 1 & 2
	SWS2153	SAS SHORTING PLUG DATA
	Z02159	UNMANNED GROUND SYS MGMT CRITERIA
837		SL3 EQUIP REQ'D FOR EVALUATION
	Z02162	REV 3 SL-4 U/M SPACECRAFT MGMT CRITERIA
	SWS2154	ATM/AM BATTERY CAPACITY TESTING
	SWS2148	EPC ACTUATOR CURRENTS
	SWS2164	SL-4 SYSTEM PROBLEM INVESTIGATION REVIEW
844	AX2146	S055 ELECTRICAL PROBLEM
852		KOHOUTEK ATM VIEWING
	SWS2183	180° ROLL MANEUVERS
866		CBRM 9 AUTODISCONNECT
867		PWR DOWN/LIMITED OPER FOR NO COOLANT LOOP
	SWS2189	SL-4 UNMANNED MGMT CRITERIA
869		REVIEW OF CHANGES TO COMMAND PROCED SL-4

HOSC AR #	JSC MAR #	TITLE
	AX2199	S055 MAIN POWER
875		S055 ELECTRICAL POWER CONFIGURATION
	SWS2203	CBRM 3 BATTERY DISCHARGE
	SWS2205	SL-4 MGMT CRITERIA
	SWS2221	TV BUS 2 OHMMETER CHECK
891		SL-4 SYS PROBLEM INVEST. & STATUS
878R1		OCCULTING MANEUVERS FOR S201
901		LOSS OF SL-3 & SL-4 DATA
	Z02238	MANNED MGT CRITERIA
	SWS2237	AM DCS ANOMALY DOY 315
	SWS2243	CONTINGENCY RENDEZVOUS
907		EPC U/D LOCK FAILURE
	SWS2246	CBRM 3 RECHG/DISCHG
940-2		CREW QUESTIONS
950P		EREP PRACTICE
913		ATM C&D COOLANT LOOP IS ERRATIC SL-3
920-6		MD-6 FLT PLAN
904R1		TAPE RECORDER DATA
914		C&D PUMP OPERATION
	SWS2284	CREW ALERT CHECK
915		S232 MANEUVERS
918		CBRM 9 RECHG COMPL ANOMALY
924		S183 MRD CHANGE
926		CBRM 5 CHG ON/OFF RELAY STUCK
	Z02328	MANNED MGMT CRITERIA REV 5
	Z02365	S054 C&D PANEL LIGHTING
	Z02367	PCG 6 CAP TEST
937		EPC PROBLEM
932		CMG OPERATIONAL ASSESSMENT
941		VEHICLE VIBRATIONS
	2403	MANNED MGMT CRITERIA REV 6
947		DATA WITH DTV OUT
949	SWS2418	AM OCV ADJUST
952		SAS 15 VOLT DROP
961		S082A T/S DOOR INDICATES IN TRANSIT
	AX2466	S082A APERATURE DOOR ANOMALY
	AX2469	S082A FILM CAMERA IMPINGEMENT CONSTRAINT
962		C&D LOOP FLOW REDUCTIONS
	SWS2509	SPIN STAB OF O.A.
972		SL-4 EVA
	AX2512	TV MONITOR OPS W/FAILED ATM C&D COOLANT LOOP
979		ATM C&D DAS ANOMALY
	SWS2513R1	ECM EVA QUASI-INERTIAL
985		SEQ FOR SECOND CMG FAILURE

HOSC AR #	JSC MAR #	TITLE
989		AM XMTR C
991		AM LL MUX NOISE PROBLEM
992		AM LL MUX NOISE PROBLEM
	AX2593	SCAN SPEC GRATING POSITION
987		MANUAL CMG HEATER CONTROL
984		"KLUNK"
	CX2625	RCS CONTAMINATION DURING EVA
	SWS2645	REV D TO FAILURE OF CMG
	Z02649	SL-4 MANNED MGMT CRITERIA
1000		RCS FOR EVA 4 CONTROL
	SWS2688	EREP ZLV TEMP CONSTRAINTS
1011	SWS2705	BAT CAP CK @ END OF MISSION
1009		EOM CONFIGURATION
	EX2721	S193A GEOS-C SUPPORT-DATA TAKE
	SWS2240	EPS MANNED MGMT CRITERIA
	Z02748	MANNED S/C CRITERIA
1016	SWS2755	CBRM9 - RECH CMPLT SIGNAL
	Z02778	SL-4 END OF MISSION FLT PLAN
1018		SL-4 POSTFLIGHT CREW DEBRIEFING
1019R1		POST SL-4 CONFIGURATION
	SWS2819	EOM ELEC TESTING
1054		CLOSEOUT PHOTOS
	Z02802	BATTERY TESTING
	AX2888	H-ALPHA-1 DOOR
1060		STOWAGE BAG FOR REVISIT
1064		PICTURES
1066		END OF MISSION TEST PLAN
	SWS2952	PCG A-H INTEGRATORS

APPENDIX 2

Sneak Circuit Analysis.

The goal of the sneak circuit analysis was to identify any condition which, due to a sneak (unwanted and potentially anomalous) electrical path, could degrade Skylab electrical performance. The Sneak Circuit Analysis performed on Skylab was imposed for reasons of safety (equipment and personnel) and mission success. The program involved:

Establishment and maintenance of a complete set of Skylab design documents.

Verification of all module interfaces.

Development of simplified schematics which were used to evaluate the activation circuitry, system sequence checks, and procedure studies.

The use of a computer as a tool in circuit analysis on programs as large as Skylab was unique. The performance of this type of task by manual methods would have been extremely difficult and inefficient considering the complexity of the Skylab electrical system.

Analysis Description.

The analysis performed included all modules of the Saturn Workshop: the Electrical Support Equipment (ESE) and the Saturn Workshop (SWS) interfaces with the Instrument Unit (IU) and Command and Service Module (CSM) were included. Those IU functions which control SWS systems were analyzed. Experiments associated with the Skylab SWS were also a part of the analysis.

The analysis continued through mission termination. ESE umbilical power and control circuits were analyzed for the time period from just prior to initiating the automatic sequence until after umbilical separation. Circuitry of the airborne modules and interfaces defined above were analyzed for the operational modes of each mission phase.

The analysis included the primary power and control circuits, switched secondary power and control circuits, switched signal circuits, command circuits, and computer interface circuits. Certain non-switched signal circuits, the grounding and most of the digital logic circuitry were excluded.

Program Concept.

The prime function was to obtain the data for the analysis, evaluate potential sneaks and ensure implementation of corrective action. This function included: analysis of the Skylab circuitry and identification of potential problems, and coordination with contractor home plants for potential sneak circuits and additional data.

A review board, consisting of a member from associated organization, was established to disposition all reports.

Operations.

The task involved the acquisition, correlation and encoding of over 4,000 detailed schematics and wiring lists for the various modules.

Eight new computer programs were developed and 17 existing programs were modified to provide assistance in performing the analysis. The purpose of these programs varied from tracking of input documents and reports to automatically drawing network trees from information in the data base. A total of 400 computer hours (IBM 360/65 and 370/155) were needed to complete the analysis effort.

A total of 1,530 change packages were received and analyzed. Of these, 312 were electrical functional changes.

Results.

The analysis resulted in the preparation of 259 Sneak Circuit Reports. Many reports described more than one Sneak Circuit condition. A significant by-product of the analysis was the identification of drawing errors. Over 300 Drawing Error Reports were released.

The Sneak Circuit Reports were reviewed and dispositioned. The disposition was as follows: 44 Sneak Circuit Bulletins; 40 Problem Reports; 91 Design Concern Reports; 17 Drawing Error Reports. Corrective actions resulting from review of reports included 20 hardware changes, 37 procedural changes, 4 documentation changes, 5 test constraints. In addition, over 45 hardware changes resulted from the Drawing Error Reports. All Sneak Circuit Reports were dispositioned and closed out. Notification of drawing errors was made to all concerned organizations involved in the test, mission control and mission support areas.

Conclusions and Recommendations.

The Sneak Circuit Analysis of the Skylab Saturn Workshop has resulted in a range of conclusions relative to the Skylab Program and a series of recommendations for the application of the analysis on future programs.

Conclusions.

The following conclusions have been drawn from the analysis:

a) In obtaining and identifying the electrical schematics for Skylab the following problems were encountered.

Not sufficient continuity between the electrical schematics and the assembly drawings.

Experimenters and prime module vendors did not provide the latest engineering into NASA's Repositories. Some of the changes come into the Repository a year after release.

Module vendors did not require sub-vendors to release their drawing to NASA's Repositories.

Top level drawings were hard to identify and some top level schematics were not available.

Had to determine continuity between terminals on terminal boards using the mechanical drawings.

End item did not have a configuration index drawing.

Prime vendor did not have a reference designation system.

b) This analysis has been program effective for reasons other than equipment and personnel safety and mission success such as:

Establishment and maintenance of a complete set of documentation for the Skylab electrical/electronics systems.

Upgrading of documentation systems as a result of drawing errors and index capabilities.

Verification of interfaces within and between modules by the use of computer programs, analysis and reports.

Development of network trees which have been used to conduct an activation survey, system sequence checks, and procedural studies.

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Recommendations.

The analysis results and conclusions indicate that sneak circuit analysis has had a major impact on the Skylab Program. Significant recommendations can be summarized as follows:

A sneak circuit analysis should be performed on future manned systems similar to Skylab and on unmanned space systems where safety, reliability or mission success dictate a requirement for high probability of sneak free operation.

The analysis should be conducted early in the program development cycle to realize the greatest benefits. The Skylab analysis was started about six months after Critical Design Review (CDR). Sneak conditions, identified later in a program, result in costly fixes, in less desirable fixes being accepted, or in the condition being dispositioned as an acceptable risk because of cost, schedule, and other program constraints.

The data collection and correlation process for future programs should be initiated early in the program cycle. For those programs where a sneak circuit analysis is indicated, the initial data requirement should specify delivery of detailed schematics, wire lists, wire tapes and other required input data prior to the time the analysis is initiated.

All end items should have a configuration index that will identify all drawings and correlate the part number to the electrical schematic where applicable. Also a document should be issued that lists all end items and part numbers.

It should be a long range goal for NASA programs to specify the delivery of automated wiring information on wire tapes. In addition to improving the efficiency of the sneak circuit analyses, other benefits to the program in the areas of configuration management, systems engineering, quality control, test and operations would be realized.

APPENDIX 3

Skylab Cluster Power Simulator - Installation through Mission Support.

I. DESCRIPTION

The Skylab Cluster Power Simulator, located at the Launch Vehicle and Power Verification Complex (LV & PVC) Facility in MSFC Building 4436, consists of twenty-six racks of equipment, an "A" frame housing eighteen (18) charger battery regulator modules (CBRMs), two (2) airlock battery modules housing four (4) power conditioning groups (PCGs) each, and an Apollo Telescope Mount (ATM) Power Transfer Distributor. The PCGs, CBRMs, and Power Transfer Distributor are flight type hardware located in an enclosed air conditioned area providing proper ambient temperature and active CBRM coolant requirements. In addition, a primary and secondary coolant unit is utilized for active cooling of the airlock module PCG components (battery, charger, and regulator) cold plates.

To provide a more detailed description of the Skylab Cluster Power Simulator, the system is divided into the following subsystems; ATM Power Subsystem, AM Power Subsystem, Command Service Module (CSM) Simulator, and Associated Electrical Support Equipment (ESE). In addition, a chronological listing of hardware buildup and checkout completion dates is provided.

A. ATM POWER SUBSYSTEM

The ATM Power Subsystem is comprised of eighteen (18) CBRMs eighteen (18) simulated solar array power supplies and solar array programmers, an ATM power transfer distributor, an ATM watt hour assembly, variable load banks, and control and display panels. Control and monitor functions are provided to allow both normal and contingency modes of power system operations.

B. AM POWER SUBSYSTEM

The Airlock Module Power System is comprised of two (2) battery modules, each housing four (4) power conditioning groups (PCG). Each PCG consisted of a battery charger. battery, and an output voltage regulator. Eight (8) simulated solar array power sources were used for battery charging. Each solar array simulator consists of a DC power supply and an associated series regulator to provide PCG battery charger input power. The PCGs are controlled from the AM EPS control and display panel (206), the AM power system switching panel (205), and the power distribution circuit breaker panel (201). These three flight type panels comprise the AM Power System Control and Display Console. The

AM Power System Control extends to the OWS, MDA, CSM, and ATM Load Buses as selected on the control and display panels. Variable loads can be applied to any or all buses to simulate various orbital load profiles.

C. CSM SIMULATOR

The Command Service Module (CSM) Simulator is comprised of simulated descent battery and fuel cell power sources, flight type CSM/MDA interface power filters, and variable loads including flight type power inverters. Control and display panels are provided to simulate flight power and load profiles.

D. ESE

The Electrical Support Equipment is comprised of ESE power supplies, a Digital Data Acquisition System (DDAS) Station, Networks Switching and Control, a Low Temperature Test Unit (LTTU), Cluster Load Banks, and a Hewlett Packard Data Acquisition System (DAS). The DDAS System utilizes magnetic tape recorders and a SEL 810 Computer for data monitoring. The H/P DAS is a self-contained unit with magnetic and paper tape recording capabilities in addition to visual data readout.

E. INSTALLATION TASKS AND CHECKOUT HISTORY

The following chronological listing identifies the major hardware tasks performed in building the Power Simulator to its present configuration. In addition, the month that completion and checkout was accomplished is noted.

1. October, 1970 - Started racks and facility installation effort.

2. May, 1971 - AM Battery Module No. 1 Delivered and Installed.

3. September, 1971

   a) Power Simulator Facility Power Installation Completed.

   b) AM Battery Module No. 2 Delivered and Installed.

   c) DDAS Station Installation and Checkout Complete.

4. November, 1971 - ESE Power Subsystem Checkout Completed.

5. December, 1971 - ATM Power Transfer Distributor Delivered and Installed.

6. March, 1972 - One-half Power System (9 CBRMs and 4 PCGs) Operational.

7. April, 1972 - Total AM Power System (8 PCGs) Operational.

8. June, 1972

    a) Total ATM Power System (18 CBRMs) Operational.

    b) Total Power System (18 CBRMs and 8 PCGs) Paralleled and Operational.

9. January, 1973 - "Upgraded" CSM Simulator Operational.

10. February, 1973 - Added H/P Data Acquisition System in Preparation for Mission Support Role.

II. TEST AND HOSC/MISSION SUPPORT ACTIVITIES

The tests performed at the Skylab Power Simulator are divided into three categories as follows: (A) Tests per Requirement Document 40M35693, (B) Special Tests, and (C) HOSC/Mission Support Tests. The following lists identify the tests and completion dates.

A. TESTS PER 40M35693

1. October, 1972 - Power Subsystems Tests (AM and ATM) and Emergency Deactivation Tests (Sections 7.1 and 7.2).

2. March, 1973 - CSM Power Subsystem Verification Tests (Section 6.7).

3. April, 1973 - Power Subsystems Parallel Operations Verification Tests AM-EPS/ATM-EPS/CSM-EPS (Sections 7.3.1, 7.3.3, and 7.3.4.

4. May, 1973 - Power System Contingency and Malfunction Modes Operation Verification Tests (Section 7.4).

5. May, 1973 - Power Systems Power Sharing Characteristics and Interface Voltage Limit Tests (Sections 7.3.7.3 and 7.3.7.5).

6. September, 1973 - Power System Bus Noise and Transient Tests (Section 7.3.7.1 and 7.3.7.2).

7. January, 1974 - ZLV-R, Solar Inertial, and ZLV-E Simulated Orbit Tests (Sections 7.3.2, 7.3.6 and 7.3.8). NOTE: Although these tests were not completed until near the end of SL-4 Mission, a representative number of simulated orbit tests for each section were completed prior to SL-1 launch.

B. SPECIAL TESTS

1. September, 1972

a) Additional AM Power Systems Bus Tests were conducted. These tests were to gain additional bus voltage and current characteristics under multiple PCG bus source conditions.

b) Conducted CBRM Tests related to CBRM source input capacitor problems.

2. November, December, 1972

a) AM Battery Recharge Tests - Forty-two days of continuous AM Battery Tests were performed. The tests were conducted to investigate the effects of reduced charge voltage and Amp-hour meter return factor on battery operation and Amp-Hour meter control. During the above tests 463 simulated Day/Night orbits (1.5 hours each) were conducted. In addition, thirteen (13) battery capacity tests were made for a total operating time of 922 hours.

b) CBRM Capacitor Tests - Conducted an investigation of the Tantalum Wet Capacitor Problems experienced by the ATM CBRMs.

C. HOSC/MISSION SUPPORT

During all Skylab missions, Power Simulator support was provided with continuous support provided during activation and deactivation periods.

The major support efforts are identified below.

May, 1973

a) Provided hardware verification for a paper Simulation Power Bus Management Problem.

b) Power Simulator "On Line" during and after SL-1 Launch. Power system configured to simulate "On Board" problem. (One OWS wing not deployed, Batteries stored)

c) A special CSM to SWS Power System Paralleling Procedure was conducted and test data transmitted.

d) On May 18, 1973, the Power Simulator AM batteries were configured to simulate on board AM battery conditions (Depth of Discharge and Temperature). These conditions were maintained and monitored continuously through June 11, 1973. The purpose of this effort was to establish battery conditions similar to Skylab in order to determine the response after the long dorment period prior to SL-1 Wing Deployment.

June, 1973

a) Conducted one-half solar array power recharge to AM batteries at end of above dormant storage period.

b) Conducted a battery capacity check to verify that Skylab battery capacity telemetry data was valid.

c) Conducted Telemetry Tests on a CBRM with both open and low resistance telemetry returns to identify problems associated with Skylab CBRM #17.

d) Conducted Special Tests on the ATM Power System to determine the effect on all other CBRM outputs if a CBRM loses regulator output power sharing remote sensing capability.

e) Provided continuous coverage during SL-2 Launch (May) and Skylab Activation and Deactivation periods.

July, 1973

Provided continuous coverage during SL-3 Launch and Skylab Activation.

August, 1973

a) A total of 110 simulated orbits (in real time with Skylab) were conducted during this period.

b) Battery capacity checks were conducted on three (3) CBRMs in real time with Skylab CBRM capacity checks. These tests were conducted to validate the Skylab Telemetry Data.

September, 1973

a) Assisted in the development and verification of a Special AM Power System Configuration for the Skylab storage period between SL-3 and SL-4 missions. This special power system configuration provides shutdown capability (VIA DCS) of the AM Power System to prevent equipment damage in the event of a coolant loop failure.

b) Supported testing of hardware verification of a concept to operate partially disabled Skylab CBRMs 3 and 5 as one "Good" CBRM. Bus characteristics and operational data were acquired under various load and orbital (solar array) configurations.

c) A total of 72 orbits were conducted in real time with Skylab.

d) Supported verification of OWS SAG 4 postulated short on SAG 4 return wire by simulation of flight data.

October, 1973

a) Assisted with additional tests related to item September-(b) above.

b) Conducted Special CBRM Tests to verify CBRM Auto Alarm indications operation.

November, 1973

Provided continuous Power Simulator Coverage during SL-4 Launch and Skylab Activation period.

December, 1973/January and February, 1974

a) Simulated orbits were run in "Real Time" with Skylab.

b) Conducted special hardware verification of Skylab closeout and power down.

c) Provided continuous support during SL-4 Deactivation.

III. CREW AND FLIGHT CONTROLLER TRAINING

In November, 1971, a requirement was identified to provide hardware and power system theory training to fifteen (15) Skylab Flight Controllers. As a follow on, in February 1972, the requirement was expanded to provide five (5) Astronauts up to fifteen (15) hours each of hardware training.

The following listing identifies the tasks required to satisfy the above requirement and their completion dates.

1. February, 1972 - Started development of "Skylab Cluster Power System Description Document" (Training Manual) 50M78001.

2. April, 1972

   a) Preliminary training plan outline completed.

   b) Twenty "Red Line" copies of 50M78001 distributed to NASA personnel for review and comments.

3. May, 1972

   a) Meeting held to conduct a final review of course material, lesson plans and proposed training sessions schedule.

   b) Classroom training aids completed (flip charts, training session outlines, etc.).

   c) Final draft of 50M78001 released for reproduction and distribution.

4. June, 1972 - Reproduction and distribution of 50M78001 completed.

5. July, 1972 - Conducted first flight controller training session.

6. August, 1972 - Conducted second and third flight controller training sessions.

7. September, 1972

   a) Conducted fourth flight controller training sessions.

   b) Astronauts J. Lousma, and O. Garriott spent approximately three hours operating the simulator hardware.

8. October, 1972

   a) Conducted the fifth Flight Controller Training Session.

   b) Astronauts A. Bean and J. Lousma spent approximately two hours operating the simulator hardware.

9. November, 1972

   a) Astronauts P. Conrad, Kerwin and Weitz spent two hours operating the simulator hardware.

   b) Conducted an abbreviated three-day training session for on-site personnel.

10. January, 1973 - Astronauts Carr, Pogue and Gibson spent three hours operating the simulator hardware.

APPENDIX 4

SEPSA Computer Program.

The Skylab Electric Power System Analysis (SEPSA) Computer Program was developed to provide a tool for simulation of the EPS performance over a wide range of operating conditions and environments. The program is completely documented in Document No. 40M35698-2, Rev. C. The program is divided into five major sections:

Attitude Trajectory Subsystem (ATS)
Solar Array Subsystem (SAS)
Charger/Battery/Regulator Subsystem (CBRS)
Power Distribution Subsystem (PDS)
Electrical Load Subsystem (ELS)

These subsystems represent the EPS of the Skylab Cluster, and the orbital trajectory and cluster attitude information needed to determine necessary attitude dependent EPS parameters. (e.g., solar array temperature).

A flow diagram of the program is shown in Figure 4.1. This diagram shows the major sections including the interaction among individual subsystems. In addition, important input and output parameters are shown.

Some of the capabilities of the program may be summarized as follows:

Generation of system performance data to evaluate the overall power capability and margin for an arbitrary set of input conditions (attitude, temperature, load condition, component failure, etc.).

Evaluation of mission proposals from an EPS standpoint.

Generation of subsystem performance data for an arbitrary set of input conditions.

Determination of the effects of various subsystem component and redundant bus failures on the EPS output.

Determination of EPS control parameters (e.g., AM Regulator Bus Voltage setting) to allow satisfactory EPS operation.

Analysis of the electrical load requirements with respect to EPS output capability, and determination of the power and energy margin level and the effects on battery capacity.

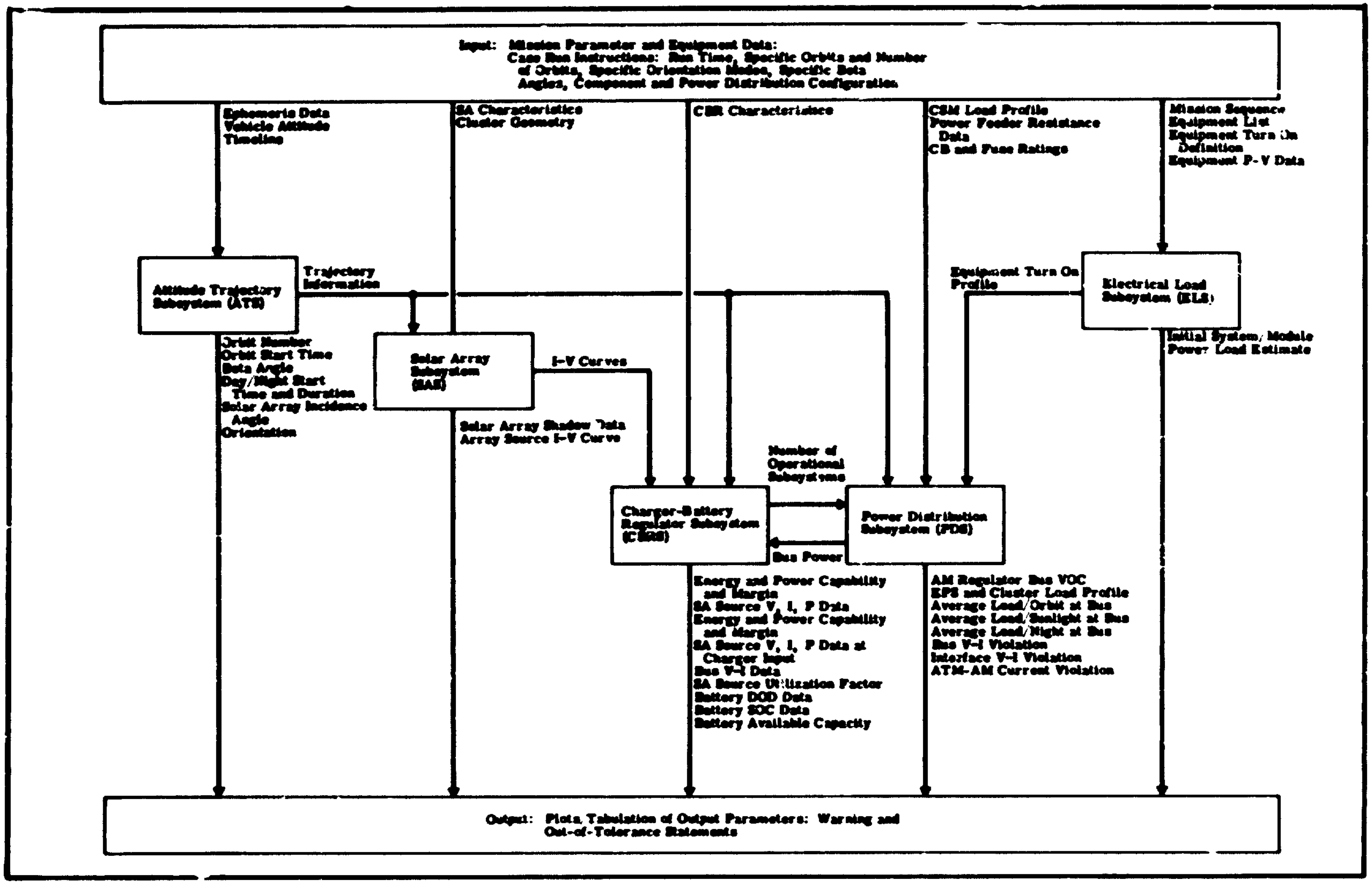


Figure 4.1. SEPSA Computer Program Flow Diagram

Determination of the sensitivity of EPS performance to varying configuration in the operational components and power distribution.

Determination of the sensitivity of EPS performance to changes in mission parameters such as power level, orientation maneuvers, and beta angle.

The capabilities of the program could be utilized for any specified time interval.

The program was utilized on a daily basis during the Skylab mission, particularly in the analysis of proposed Z-LV-E and quasi-inertial (Kohoutek viewing, JOP-13, etc.) attitude modes. It was also used on an around-the-clock basis during the critical period following SL-1 launch when one OWS solar array wing was lost and the other was still undeployed. The program proved to be a valuable tool in mission profile analysis and power management.

APPENDIX 5

Power Management Program

Immediately after liftoff it was realized that the total cluster power system capability would be substantially reduced from that used in premission planning and imperative that real time power management activities be initiated. The need for power management was urgent and complicated by the contingency procedures required by the other cluster subsystems.

Electrical power system contingency analyses performed prior to the liftoff of the SL-1 vehicle provided the basis for the initial power management techniques. However, since the exact configuration of the orbital cluster had not been analyzed in the contingency analyses, it became evident that different and more stringent techniques would be required to insure the integrity of the ATM power system while decisions were being made regarding possible additions to the power system capability.

Due to the large number of possible load configurations, and the complexity of the subsystem interactions, many of the techniques available for power management had to be scrutinized by all Skylab disciplines prior to use. During the period, from DAY 1 through DAY 11, it was necessary to maneuver the vehicle away from the planned solar inertial attitude in order to cool the OWS structure left exposed when the meteoroid shield was lost. Since the ATM solar array output capability was reduced as a function of varied sun incident angles, varying power management techniques were required for each different vehicle orientation.

The premission planning required that the management techniques be available for use during specified peak loading periods and contingency situations. It became evident due to reduced power availability that power management would be required for the entire mission. Since the power system integrity was dependent on the orbit by orbit management, the task was a 24-hour per day, 7 day per week task.

Neither the facility nor the tools for real-time power management were planned premission and therefore it was necessary to establish the facility and develop the tools at the same time the techniques were being implemented.

In determining the techniques required to properly manage the power system it was necessary to be able to constantly monitor the electrical power system parameters, to know the exact vehicle electrical load configuration at all times and to have a knowledge of the subsystem requirements for each mission phase. Since the data and discipline contact was available at the HOSC the ideal location for the facility was in the HOSC.

Space was reserved in the HOSC to house the power management team.

It was evident that many of the computer programs developed for premission load predictions and postmission analysis would be extremely useful for real-time power management. An effort that resulted in a remote access terminal being installed at HOSC was approved by NASA. The terminal was composed of a key board for making inputs and a Cathode Ray Tube (CRT) for verification of the inputs and displaying the output data. In addition to the computer terminal an electronic calculator was secured for use in data evaluation. Immediately upon receipt of the necessary equipment, the team began a continuous support effort that was to serve with little change for the entire Skylab mission.

The tasks essential to good power management included the following:

1. Evaluate the daily flight plan or plans for compatibility with the power system.

2. Evaluate all planned maneuvers for effect and forward the information to the groups required to perform capability and DOD predictions. Evaluate the predicted DODs and recommend off-loading or mission changes.

3. Review and comment on the daily Execute Package which contained the data uplinked to the crew for execution of tasks.

4. Request the actual ATM CBRM DODs and actual loads during all off-nominal pointing modes.

5. Record all critical EPS parameters for each off-nominal pointing mode on a summary sheet.

6. Continuously monitor the total electrical load including the transfer loads and report significant deviations from the predicted loads.

7. Review the 7-day flight plan forecast for planned operations requiring special attential by the EPS MSG.

Summary flight plans were issued for review each day of the manned missions. On days where a possibility existed that a planned task would be cancelled both a "prime" and an "alternate" flight plan were generated and issued for review; e.g., an EREP pass was sometimes cancelled in near real-time due to inclement weather cloud cover) over the area of interest. Since the flight plans were completed by the JSC team and then reviewed by all disciplines, numerous changes were required before the final plan was generated. The normal iteration process resulted in three to four revisions of the flight plan being issued for review but sometimes as many as eight flight plan revisions were issued for a single day.

To insure that the scheduling of astronaut tasks described by the summary flight plan was compatible with the power system capability a predicted power profile was constructed for each flight plan. Immediately upon receipt of the flight plan the astronauts schedule for the day was translated to computer form and entered into the computer system using the remote access terminal. The accuracy of the computerized flight plan was verified and the loads, not depending on the astronaut activity, were scheduled to complete the load profile. The principle loads scheduled in this manner were heater duty cycles, unattended experiments, ground controlled loads, and the CSM load requirements. After completion of these inputs from the summary flight plan the load profile was computed using the SEPSA computer program.

One of the outputs from the SEPSA program was a load profile for the entire mission day on a six minute increment. In addition to the total load, the load was divided by module and by load bus. Evaluation of the tabular data revealed reasons for the frequent load changes and the location of the major contributions to the total load for each of the defined tasks. It was possible to refine the load sequencing criteria and improve the accuracy of the program by comparing these predicted loads to the actual bus loads and total cluster loads during the mission.

Since the remote access terminal used to compute the predicted load profile did not have printing capability, the data was displayed on the CRT and recorded manually. The total cluster load profile was then plotted for release to disciplines interested in the incremental load; Figure 5.1 is an example of the predicted load profile prepared for each summary flight plan. Since the power system capability for each mission was given on an orbital average basis, it was necessary to average the predicted loads for the same period to insure that the system integrity was protected during each orbit. A computer program was written to average the incremental loads on an orbital basis. In addition to the total cluster orbital average load the tabular data included the average loads per module. Table 5.I is the orbital average loads for the mission day that was plotted in Figure 5.1.

The MSFC Skylab Mission Status Group maintained near real-time status charts of key parameters for each system. These charts reported the parameters for each revolution of the Skylab vehicle. To keep the EPS data consistent a computer program was created to average the total cluster load by revolution. This predicted average load per revolution was plotted by the Mission Status Group on a plot in the

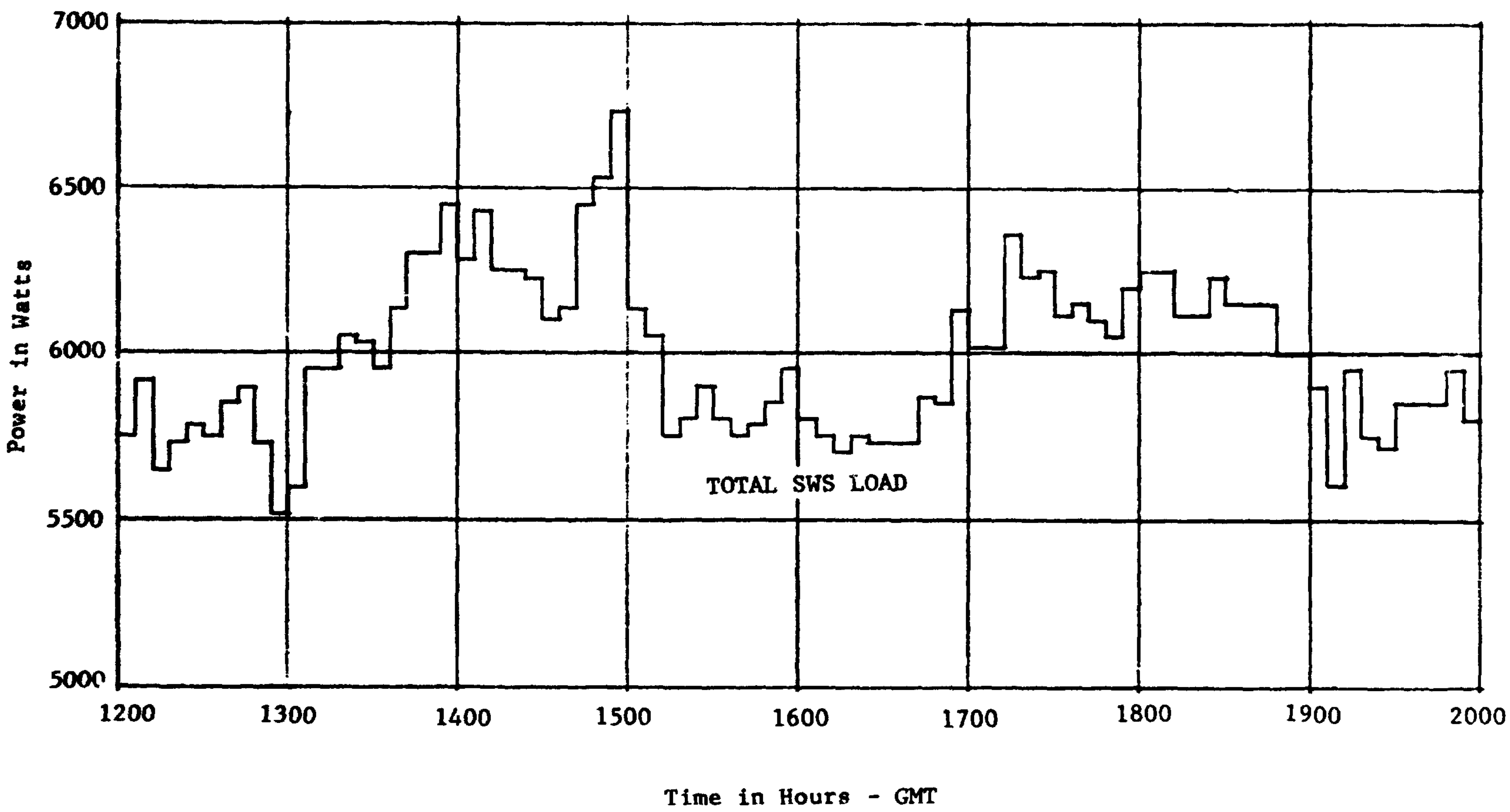


Figure 5.1A Typical Load Profile

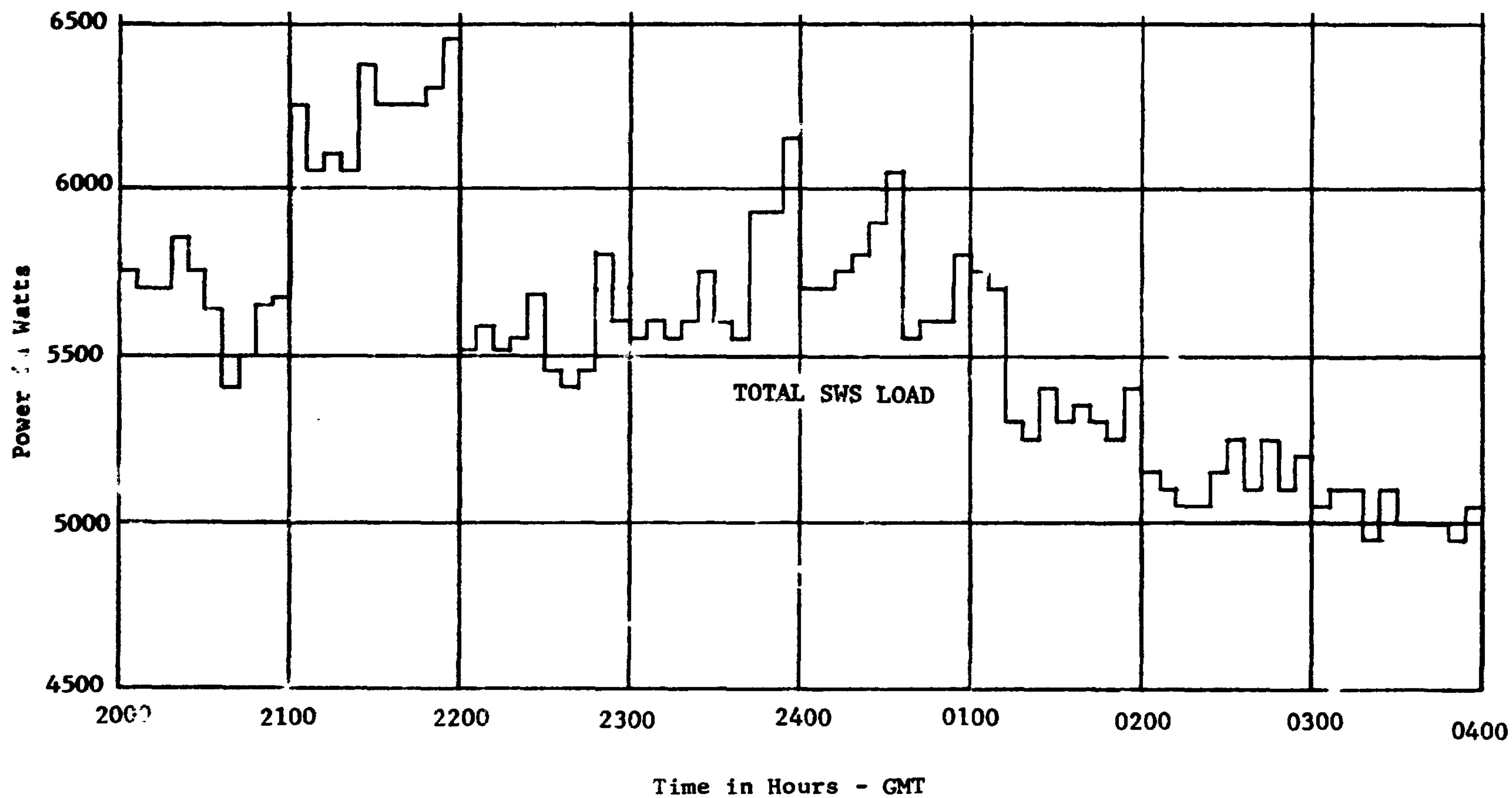


Figure 5.1B Typical Load Profile

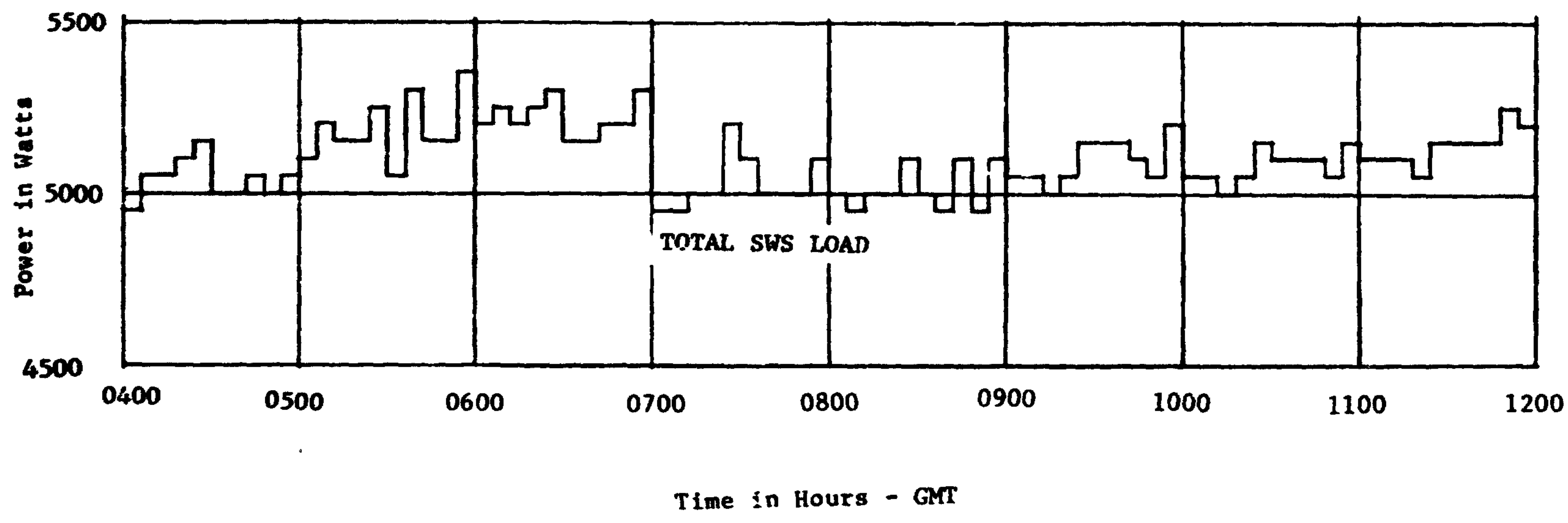


Figure 5.1C Typical Load Profile

ORBIT	TOTAL	ATM	AM	OWS	CM	EPS	TIME ORBIT STARTS
772	5525	2003	1490	797	1000	236.0	11.2
773	6073	2041	1904	901	1000	227.0	12.8
774	5971	205[illegible]	1937	752	1000	227.0	14.3
775	5932	2055	1840	[illegible]	1000	227.0	15.9
776	6135	2059	1834	1009	1000	234.0	17.4
777	5748	2053	1728	736	1000	[illegible]	19.0
778	5807	2035	1668	877	1000	227.0	20.5
779	5576	1913	1585	852	1000	227.0	22.1
780	5793	2059	1699	808	1000	227.0	23.6
781	5214	1913	1384	680	1000	236.4	25.2
782	5049	1911	1372	539	1000	227.0	26.7
783	5126	1913	1466	521	1000	227.0	28.3
784	5165	1915	1496	528	1000	227.0	29.9
785	5020	1908	1362	522	1000	227.0	31.4
786	5070	1915	1373	574	1000	227.0	33.0
787	5138	1911	1371	629	1000	227.0	34.5
AVG.	5515	1977	1588	721	1000	229	

PEAK PWR IS 6429 WATTS @ [illegible].9 HOURS

Table 5.I. Average Load Per Orbit

chartroom and compared to the actual loads which were computed from real-time data obtained during ground station passes by the MSFC electrical console operations. Figure 5.2 is a plot of the predicted load per revolution with the actual computed loads shown as a dashed line. Power system capability for the solar inertial revolutions is also plotted on the chart for reference.

If the computed load profile predicted a load, for a particular revolution, that exceeded the capability, then suggested techniques were submitted to JSC for consideration and use. Off-loading, AM Reg Bus OCV adjustment, or rescheduling were the three techniques used. Prior to reviving the AM EPS it was necessary to continuously manage the vehicle to allow the astronauts to accomplish the desired tasks. However, after the OWS solar wing was deployed on DAY 25 the power system had sufficient capability to permit relaxation of power management during the solar inertial mode for the majority of the revolutions. By adjusting the Reg Bus OCV only for major changes, such as CSM transfer to internal power or large changes in beta angle (10 to 15 days of change at approximately 4 degrees per day) it was possible to maintain a positive power margin at all times without daily management techniques. The one exception to this was that off-loading of lights and fans in the OWS was suggested during the EVAs to compensate for the increase in load requirement caused by the EVA lights and the astronaut life support equipment.

The predicted load profile was also useful for real-time support. It provided the basis for evaluating the actual load for proper operation of the electrical components. If the loads were significantly higher than the predictions indicated, a possible anomalous situation existed and an investigation was begun. Also the difference between the predicted loads and the actual loads indicated a change in astronaut operating procedure that was important to other disciplines, (e.g., when the OWS temperatures began to increase, the astronauts would use only half of the interior lights and would switch them to the low intensity setting). This was detectable by noting a reduction in OWS bus current from the predicted value. This change in operating procedure was very important for proper environmental control as was verified by crew voice transmissions.

In addition to analyzing the summary flight plan the power management area received the maneuver charts for each planned excursion from the solar inertial attitude. This chart was generated by JSC and forwarded to MSFC for review. The chart was titled "H-Bar Maneuver Pad" but was commonly known as the "Pie Chart" due to the fact that the maneuver description divided a circle into segments resembling pieces of pie. The Pie Chart defined the duration and location in the orbit of the off-nominal pointing, the maneuver rates and times for the transition to the off-nominal attitude, the excursion from nominal

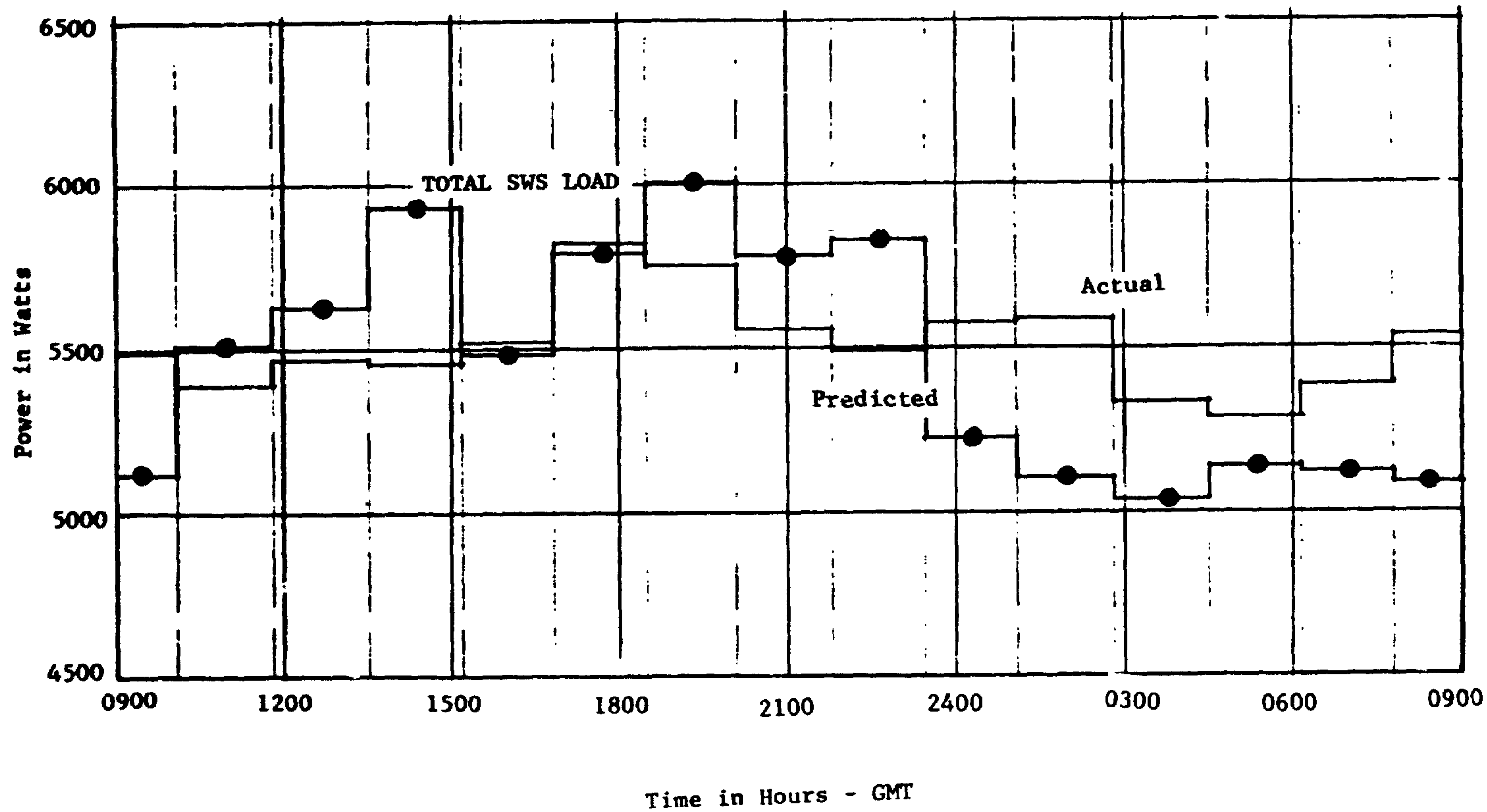


Figure 5.2 Average Load per Revolution

in each the X, Y and Z axis, and the time of the planned pass. Upon receipt of the Pie Chart it was distributed for review and computation of the predicted DODs. Along with the pie chart the power management personnel also provided the predicted load for each phase of the pass to be used in the computation. SEPSA computer programs were originally designed and used for premission and postmission support to compute the predicted DODs.

The power management personnel compared the predicted DODs to the maximum allowable DOD constraints to determine if the constraints were violated. If a violation or near violation was indicated, power management techniques were suggested and the DODs were recomputed to reflect those techniques. This iterative process was continued until the maximum predicted DODs for both the PCGs and CBRMs were within the constraints. Once the proper combination of OCV adjustment and off-loading was established to protect the integrity of both the CBRMs and the PCGs the definition of this configuration was forwarded to JSC. Table 5-II is an example of the form used to record the DOD predictions, typical predictions have been added to the form for comparison.

The Flight Support Team also had a computer program used for cluster load and DOD predictions. Basically the system used two programs, PEARL and PANACEA, plus manually calculated shadowing co-efficients to compute the predicted values. The predictions were recorded in a report called "EPS Evaluation" which was forwarded to HOSC each day, when applicable, for review. Many times the MSFC and the JSC predictions were run at different Reg Bus OCV or different combinations of off-loading or both; in these cases the DOD predictions appeared to be different and understandably so. If both predictions resulted in the protection of the integrity of the power system then the selection of the power system configuration was left to the discretion of the electrical representative on the flight team. If, however, the two centers both used the same vehicle power system configuration and one of the programs indicated a violation of the maximum DOD criteria, then additional power management techniques were suggested until both programs indicated predicted DODs below the maximum allowable criteria. Table 5.III shows a comparison between and the actual DODs for a typical EREP pass.

Each day a copy of the "Execute Package" which contained all the data sent to the crew via the onboard teleprinter was approved. This data included the summary flight plan for the day, a detail flight plan for each astronaut, temporary and permanent general messages and check list updates. The power management personnel reviewed these packages for accuracy. All comments to the Execute Package were coordinated with other MSGs prior to being forwarded for action.

EREP-23

DAY 240

REG BUS 1 OCV 29.3 REG BUS 2 OCV 29.3

GROUND OFF LOADING MDA WALL HTRS CREW OFF LOADING (HK90A) NO

PIE CHART REV DISTL PREL

C B R M					
	%	AH		%	AH
1	33.7	6.74	10	31.6	6.32
2	32.6	6.52	11	34.1	6.82
3			12	32.0	6.40
4	33.6	6.72	13	32.3	6.46
5			14	32.7	6.54
6	31.5	6.30	15	34.5	6.90
7	32.4	6.48	16	32.2	6.44
8	32.5	6.50	17	32.2	6.44
9	31.0	6.20	18	31.6	6.32

P C G		
	%	AH
1	33.9	11.19
2	33.9	11.19
3	30.2	9.97
4	32.7	10.79
5	34.9	11.52
6	30.2	9.97
7	40.0	13.20
8	34.0	11.22

Table 5. II EREP DOD Predictions

EREP 21, DAY 238

CBRM NO	ACTUAL DOD %	SEPSA PRED %	PANACEA PRED %	CBRM NO	ACTUAL DOD %	SEPSA PRED %	PANACEA PRED %
1	34.7	34	*	10	31.4	33	*
2	33.2	34	*	11	35.9	36	*
3	-	-		12	33.1	33	*
4	34.1	34	*	13	32.7	33	*
5	-	-		14	33.2	34	*
6	33.0	33	34	15	35.5	35	*
7	34.1	33	*	16	33.4	33	*
8	34.4	34	*	17	33.0	33	*
9	32.7	32	*	18	33.4	32	*

PCG NO.	ACTUAL DOD %	SEPSA PRED %	PANACEA PRED %
1	24.8	28	37
2	25.7	28	*
3	26.2	26	*
4	26.5	28	*
5	30.5	28	*
6	25.7	27	*
7	32.0	29	37
8	27.7	28	*

*JSC ONLY PREDICTED DOD FOR WORST CASE BATTERIES.

Table 5.III MSFC-JSC DOD Prediction Comparison

After each maneuver of the vehicle to an off-nominal pointing mode, the actual battery DOD was computed for the CBRM batteries. The data was obtained from MDRS in near real-time. Since the CBRMs did not have an amp-hour integrator as a design feature, the battery currents for each CBRM were integrated during the period of interest to determine the deepest depth-of-discharge. Additionally, the actual load requirements for each time period used in computing the predicted DODs were computed for comparison to the predicted load values.

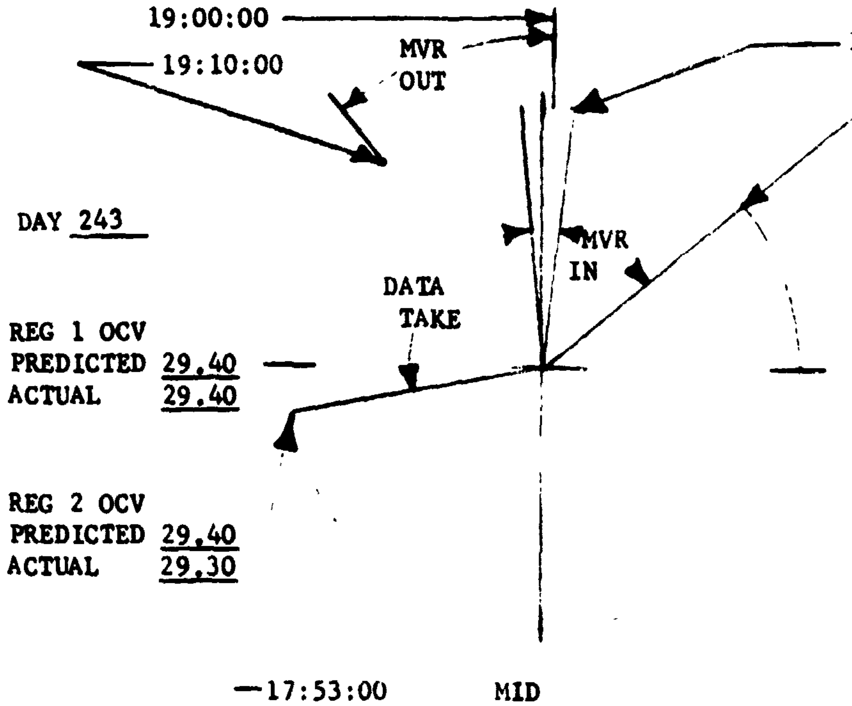
A permanent record was maintained for all the off-nominal pointing mode orbits in the form of a "Summary Chart" for each period. These Summary Charts were reviewed by MSFC management periodically when decisions were required concerning the power system operation. The summary charts list the reason for the pass, the geometry of the maneuvers, comparison of actual values versus the predictions and other data of interest. An example of the Summary Charts is included here as Table 5.IV.

Special team attention was given to periods of peak loading, such as, EREP passes and astronaut EVAs. Where necessary, power management techniques were suggested real-time to eliminate undersirable conditions before permanent damage to the power system occurred. The power management personnel responded as required to all the action requests assigned. (Appendix 1)

In order to give visibility for long range manpower and computer requirements planning, the seven-day mini-summary flight plan which summarized the major tasks planned for that period was reviewed. Planned tasks that indicated possible violation of the power system constraints were noted and preliminary investigation of the task was begun.

In retrospect the decision to assemble the power management team for near real-time mission support was instrumental in insuring the orderly attainment of the mission support goals. The procedures developed for Skylab power management would be of value to flight support teams preparing for support of future large spacecraft.

EREP- 26



PIE CHART REV FINAL

DATA TAKE LENGTH

97° 25 MIN

TOTAL Z-LV DURATION

109° 25 MIN

Z-LV CENTER 227°

BETA ANGLE -56.06°

NO	PRE-DICTED %	ACTUAL %	ACTUAL AMP HOURS	NO	PRE-DICTED %	ACTUAL %	ACTUAL AMP HOURS
1	3[illegible] 8	37.5	7.43	10	31.9	33.5	6.69
2	33.2	34.9	6.98	11	34.4	38.4	7.68
3	-	-	-	12	31.5	33.6	6.72
4	33.3	36.0	7.20	13	31.7	33.2	6.61
5	-	-	-	14	32.4	36.2	7.23
6	32.6	35.0	7.00	15	33.7	36.5	7.29
7	32.3	34.6	6.91	16	32.3	34.7	6.93
8	32.8	36.0	7.20	17	31.8	3[illegible].7	6.73
9	31.0	33.9	6.77	18	30.6	35.3	7.06

NO	PRE-DICTED %	ACTUAL %	ACTUAL AMP HOURS
1	39.4	42.7	14.09
2	39.4	41.6	13.73
3	35.8	42.7	14.09
4	38.0	42.6	14.06
5	39.3	32.9	10.86
6	35.6	28.9	9.54
7	43.1	33.5	11.06
8	39.0	30.1	9.93

LOAD SUMMARY

NOMENCLATURE	SUNSET TO NOON		NOON TO DATA END		DATA END TO SUNRISE		SUNRISE TO SUNRISE	
	PRED	ACTUAL	PRED	ACTUAL	PRED	ACTUAL	PRED	ACTUAL
TOTAL BUS POWER	5800	5823	6100	6211	5320	5640	5450	5490
ATM LOAD	2040	1962	1930	1922	1860	1835	1900	2018
AM LOAD	2310	2440	2720	2820	2060	2470	2100	2100
CSM LOAD	1100	1071	1100	1097	1100	99[illegible]	1100	1040
GMT TIMES:	16.5	17.4	17.5	17.8	17.9	18.3	18.4	19.9

Table 5.IV EPS Summary Charts

APPENDIX 6

HOSC Monitoring Description.

Data for HOSC monitoring was available in many forms. Figure 6.1 illustrates, in a simplified block diagram, the types of data transmitted by Skylab, its flow through the data retrieval system, and the various presentation methods used by HOSC personnel.

The methods of display utilized most extensively by the Electrical Mission Support Group were the MOPS and the OSR console. Data from MOPS was for specific TM data and was defined in real time to assist in performance analysis when the real time OSR console displays were inhibited and for resolution of problems by retrieval of stored data. The use of MOPS was restricted in all other cases to priority items. Generally, the display formats were pre-defined by NASA/JSC, however, real time requests for contingency periods permitted construction of specific plots and graphic displays for a limited time. These required a new request for each application. The MOPS response generally was rapid except when JSC priorities restricted it.

Real time OSR console displays were limited to the daily defined station coverage times throughout the mission. The effectiveness of monitoring was acceptable with the coverage that existed.

Prior to the launch of SL-1 all HOSC real time displays were defined by: device, limits to be detected, parameter to be displayed, and display format for D/TV.

Monitor equipment consisted of a four (4) rack console with the devices located as illustrated in Figure 6.2. Figures 6.3 through 6.6 typify the displays on each device which were used most throughout the mission. Also shown are the predicted limits used to monitor the parameter.

In addition to these display devices, the OSR console and associated Mission Support Group Work Area (CWA) were equipped with the following voice monitoring channels:

GOSS (crew voice) (listen only)
Flight Director (listen only)
Networks (intercom)
Operations Director (HOSC)
FOMR (NASA/MSFC reps at JSC)
Various conference loops

With the exception of occasional display aborts caused by computer anomalies within HOSC or JSC all devices and monitoring equipment functioned sufficiently well to permit performance monitoring and anomaly detection and resolution in a timely manner throughout the mission.

Table 6.I is a typical console log maintained in real time by the operator on duty.

Table 6.II lists the Skylab EPS Power-Down events for the final storeage of the system at the end of SL-4.

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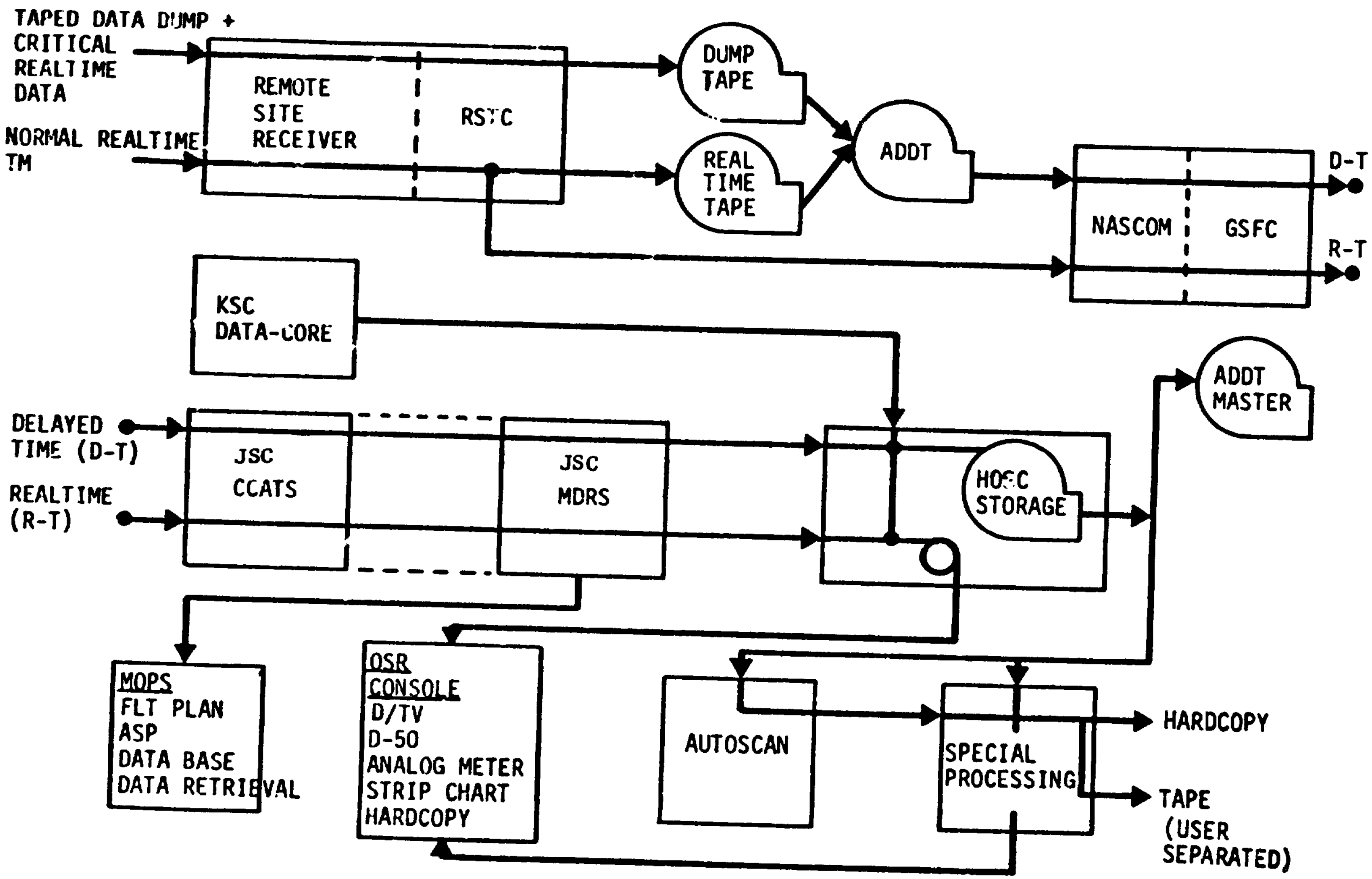


Figure 6.1 Skylab Data Retrieval System

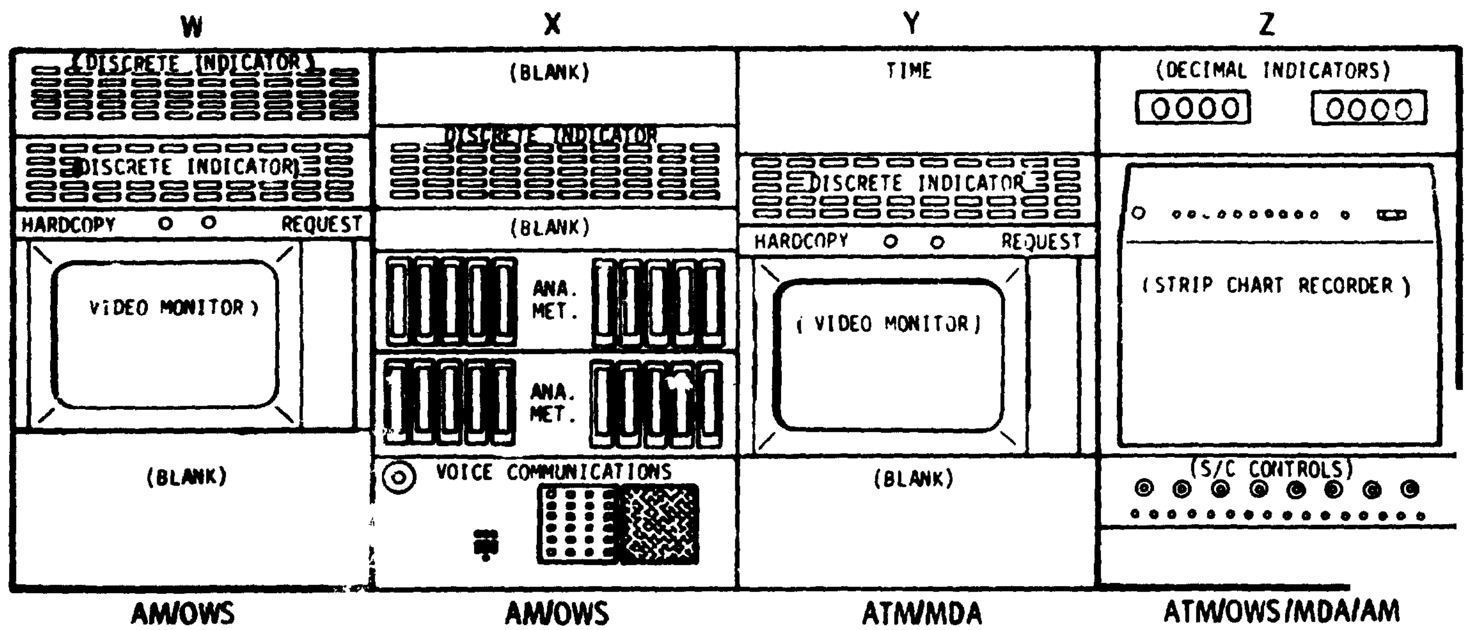


Figure 6.2 Electrical System OSR Console Layout

1312	BTY 1 OFF K0111-524 AMBER-R	BTY 2 OFF K0112-524 AMBER-R	BTY 3 OFF K0113-524 AMBER-R	BTY 4 OFF K0114-524 AMBER-R	BTY [illegible] K011[illegible] AMBER-[illegible]	BTY 6 OFF K0116-525 AMBER-R	BTY 7 OFF K0117-525 AMBER-R	BTY 3 OFF K0118-525 AMBER-R	AM [illegible] 1-REG 2 K[illegible]7-509 AMBER-[illegible]	AM [illegible] 2-REG 1 [illegible]78-509 AMBER-[illegible]
1322	PCG 1 OFF K0159-524 AMBER-N	PCG 2 OFF K-160-524 AMBER-N	PCG 3 OFF K0161-524 AMBER-N	PCG 4 OFF K0162-524 AMBER-N	PCG 5 OFF K0163-525 AMBER-N	PCG 6 OFF K0164-525 AMBER-N	PCG 7 OFF [illegible]165-525 AMBER-N	PCG 8 OFF K0166-525 AMBER-N	1 REG/XFER-[illegible] K0175-[illegible] AMBER-R	2 REG/XFER-[illegible] K0176-50[illegible] AMBER-R
1332	SAS 1 TO PCG 2 K0103-524 AMBER-R	SAS 2 TO PCG 3 K0104-524 AMBER-R	SAS 3 TO PCG 4 K0105-524 AMBER-R	SAS 4 TO PCG 1 K0106-524 AMBER-R	SAS 5 TO PCG 6 K0107-525 AMBER-R	SAS 6 TO PCG 7 K0108-525 AMBER-R	SAS 7 to PCG 8 K0109-525 AMBER-R	SAS 8 TO PCG 5 K0110-525 AMBER-R	1 ATM/XFER-OP[illegible] K0169-509 AMBER-R	[illegible]/XFER-OPEN [illegible]0-509 [illegible]BER-R
1342	1 SEC AH METER K0127-524 AMBER-R	2 SEC AH METER K0129-524 AMBER-R	3 SEC AH METER K0129-524 AMBER-R	4 SEC AH METER K0130-524 AMBER-R	5 SEC AH METER K0131-525 AMBER-R	6 SEC AH METER K0132-525 AMBER-R	7 SEC AH METER K0133-525 AMBER-R	8 SEC AH METER K0134-525 AMBER-R	1 [illegible] PWR OFF K0[illegible] AMBE[illegible]	2 AM [illegible]VS PWR OFF [illegible]83-538 AMBE[illegible]
1352	1 CHG RATE LO K0135-524 AMBER-R	2 CHG RATE LO K0136-524 AMBER-N	3 CHG RATE LO K0137-524 AMBER-N	4 CHG RATE LO K0138-524 AMBER-N	5 CHG RATE LO K0139-525 AMBER-N	6 CHG RATE LO K0140-525 AMBER-N	7 CHG RATE LO K0141-525 AMBER-N	8 CHG RATE LO K0142-525 AMBER-N	SGL PT GND-AM K0181-509 AMBER-R	[illegible] SYS CNT[illegible] K0173-5[illegible] AMBER-R

1462		7081 VDC M043-702 LIM: 4.9 TO 5.0 GREEN-N	7031 VDC M527-702 LIM 26 TO 30.5 GREEN-N	7016 VDC M525-702 LIM 26 TO 30.5 GREEN-N	7015 VDC M523-702 LIM: 26 TO 30.5 GREEN-N	7014 VDC M521-702 LIM: 26 TO 30.5 GREEN-N	7013 VDC M519-702 LIM: 26 TO 30.5 GREEN-N	7012 VDC M517-702 LIM: 26 TO 30 5 GR[illegible]N-N	7011 VDC M019-702 LIM 28.3 TO 30.5 GREEN-N	7011 AMP M023-702 LIM 0 TO 70 AMBER-N
1472			7041 VDC M528-702 LIM 26 TO 30.5 GREEN-N	7026 VDC M526-702 LIM: 26 TO 30.5 GREEN-N	7025 VDC M524-702 LIM: 26 TO 30.5 GREEN-N	M522-702 LIM 26 TO 30 5 GREEN-N	702[illegible] VDC M520-702 LIM: 26 TO 30.5 GREEN-N	7[illegible] VDC M518-702 LIM: 26 TO 30.5 GREEN-N	7021 VDC M020-702 LIM 20 [illegible] TO 30 5 GREEN-N	[illegible] AMP M02[illegible] 702 LIM [illegible] TO 70 AMBER-R
1482				SUN PRESENCE K015-702 AMBER-N	BATT 4 RECHG K347-702 GREEN-N	BATT 1 [illegible]CHG K344-70[illegible] GREEN-N	BATT 6 RECHG K356-702 GREEN-N	BATT 10 REC[illegible] K361-702 GREEN-N	BATT 12 RECHG K353-702 GREEN-N	BATT 11 [illegible] K352-70[illegible] GREEN-N
1492					BATT 5 RECHG K343-702 GREEN-N	BATT 2 RECHG K345-702 GREEN-N	BATT 7 RECHG K357-702 GREEN-N	BATT 17 RECHG K360-702 GREEN-N	BATT 13 RECHG K354-702 GREEN-N	BATT 10 RECHG K351-702 [illegible]EEN-N
1502					BATT 15 RECHG K349-702 GREEN-N	BATT 3 RECHG K346-702 GREEN-N	BATT 8 RECHG K358-702 GREEN-N	BATT 16 RECHG K359-702 GREEN-[illegible]	BATT 14 RECHG K355-702 GREEN-N	BA[illegible] 9 RECHG K350 702 GREEN-N

Figure 6.3a Typical "W" Section Discrete Indications

1362	1 DISCH LMT-INBT K0119-524 AMBER-N	2 DISCH LMT-INBT K0120-524 AMBER-N	3 DISCH LMT-INBT K0121-524 AMBER-N	4 DISCH LMT-INBT K0122-524 AMBER-N	5 DISCH LMT-INBT K0123-525 AMBER-N	6 DISCH LMT-INBT K0124-525 AMBER-N	7 DISCH LMT-INBT K0125-525 AMBER-N	8 DISCH LMT-INBT K0126-525 AMBER-N	EREP BUS 1-ON K0192-538 GREEN-N	EREP BUS 2-ON K0193-538 GREEN-N
1372	1 CHGR-BYPASS K0143-524 AMBER-R	2 CHGR-BYPASS K0144-524 AMBER-R	3 CHGR-BYPASS K0145-524 AMBER-R	4 CHGR-BYPASS K0146-524 AMBER-R	5 CHGR-BYPASS K0147-525 AMBER-R	6 CHGR-BYPASS K0148-525 AMBER-R	7 CHGR-BYPASS K0149-525 AMBER-R	8 CHGR-BYPASS K0150-525 AMBER-R		
1382	REG 1 TO BUS 2 K0151-524 AMBER-R	REG 2 TO BUS 2 K0152-524 AMBER-R	REG 3 TO BUS 2 K0153-524 AMBER-R	REG 4 TO BUS 2 K0154-524 AMBER-R	REG 5 TO BUS 1 K0155-525 AMBER-R	REG 6 TO BUS 1 K0156-525 AMBER-R	REG 7 TO BUS 1 K0157-525 AMBER-R	REG 8 TO BUS 1 K0158-525 AMBER-R		
1392	1 CHG MODE-TLMT K0184-524 AMBER-R	2 CHG MODE-TLMT K0185-524 AMBER-R	3 CHG MODE-TLMT K0186-524 AMBER-R	4 CHG MODE-TLMT K0187-524 AMBER-R	5 CHG MODE-TLMT K0188-525 AMBER-R	6 CHG MODE-TLMT K0189-525 AMBER-R	7 CHG MODE-TLMT K0190-525 AMBER-R	8 CHG MODE-TLMT K0191-525 AMBER-R		
1402	1 BTY CHG-CUTOFF K0321-512 AMBER-R	2 BTY CHG-CUTOFF K0327-512 AMBER-R	3 BTY CHG-CUTOFF K0337-512 AMBER-R	4 BTY CHG-CUTOFF K0338-512 AMBER-R	5 BYT CHG-CUTOFF K0329-512 AMBER-R	6 BTY CHG-CUTOFF K0334-512 AMBER-R	7 BTY CHG-CUTOFF K0349-512 AMBER-R	8 BTY CHG-CUTOFF K0350-512 AMBER-R		

1412	DISC ANT-DPLYD K0102-502 GREEN-R			SAS WGF 1 SECURE K7212-432 GREEN-R	SAS G 1 VOLT NOK M0101-524 LIM 55 TO 120 AMBER-N	SAS G 2 VOLT NOK M0102-524 LIM 55 TO 120 AMBER-N	SAS G 3 VOLT NOK M0103-524 LIM. 55 TO 120 AMBER-N	SAS G 4 VOLT NOK M0104-524 LIM 55 TO 120 AMBER-N	OWS BUS 1 V NOK M7002-440 LIM.24.8 TO 29 3 RED-N	OWS BUS 1 I NOK M7004-440 LIM N/A TO 60 AMBER-N
1422	DPLY BUS-PERMSSN K0323-512 GREEN-R			SAS WGF 2 SECURE K7211-432 GREEN-R	SAS G 5 VOLT NOK M0105-524 AMBER-N	SAS G 6 VOLT NOK M0106-524 LIM: 55 TO 120 AMBER-N	SAS G 7 VOLT NOK M0107-524 LIM 55 TO 120 AMBER-N	SAS G 8 VOLT NOK M0108-524 LIM. 55 TO 120 AMBER-N	OWS BUS 2 V NOK M7003-440 LIM 24 8 TO 29 3 RED-N	OWS BUS 2 I NOK M7005-440 LIM. N/A TO 60 AMBER-N
1432	DPLY BUS-ARM K0328-512 GREEN-R			SAS WGF 1 NOT FD K7213-432 GREEN-N	PRI LOGIC PS NOK M7010-436 LIM 4.75 TO 5.25 AMBER-N	SAS LOG PS NOK M7011-436 LIM.4.75 TO 5.25 AMBER-N				
1442	1 DA MTR-PAYOUT K0003-544 GREEN-N	2 DA MTR-PAYOUT K0004-544 GREEN-N		SAS WGF 2 NOT FD K7214-432 GREEN-N						
1452	1 DA DPLYMT-LOCK K0001-544 GREEN-N	2 DA DPLYMT-LOCK K0002-544 GREEN-N								

Figure 6.3b Typical "X" and "Y" Section Discrete Indications

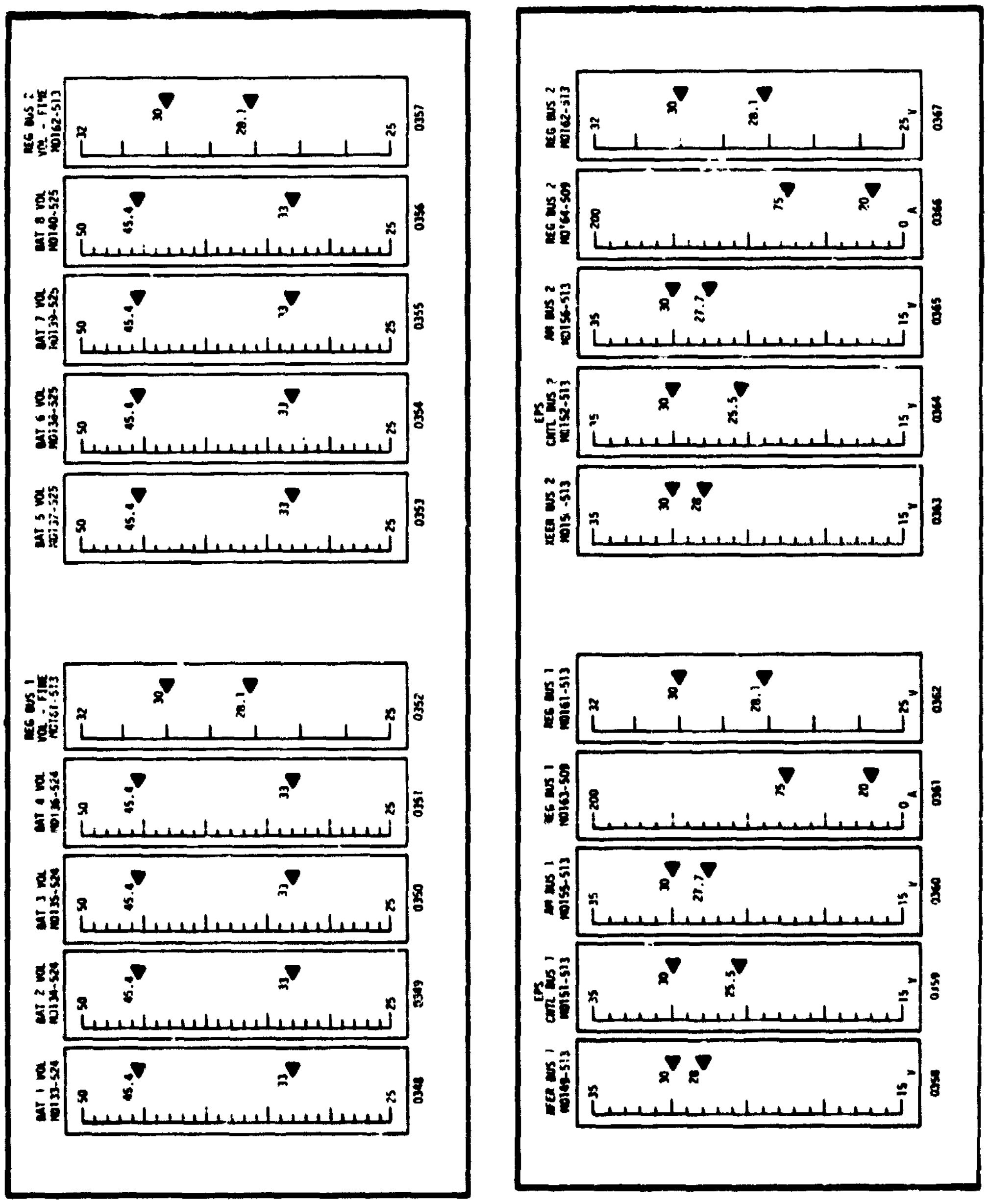


Figure 6.4 Typical Analog Meter Displays

```
SP801                                  :  :  :   UT
                  SAS DEPLOYMENT
   POSITION @                        POSITION @
   [ G ]   WG 1 SECT 1 WG 2   [ J ]
   [ H ]   WG 1 SECT 2 WG 2   [ K ]
   [ I ]   WG 1 SECT 3 WG 2   [ L ]

   VOLTS                        VOLTS
   [ Q ]   1  FAIR-EBW FU 2   [ R ]
   [ S ]   1 WG SE EBW FU 2   [ T ]

   VOLTS     HI LEVEL MUX     VOLTS
   [ E ]   E    REF HI     T  [ F ]

   VOLTS                        AMPS
   [ A ]      OWS BUS 1       [ C ]
   [ B ]      OWS BUS 2       [ D ]
   [ O ]       AM BUS 1       [ M ]
   [ P ]       AM BUS 2       [ N ]
```

801

	MEAS.	MEAS. TITLE	LIMITS	REDLINE MIN	REDLINE MAX
A.	M7002-440	PDCS OWS BUS 1 V	0 to 35	24.8	29.6
B.	M7003-440	PDCS OWS BUS 2 V	0 to 35	24.8	29.6
C.	M7004-440	PDCS OWS BUS 1 CUR	0 to 140	60	MAX
D.	M7005-440	PDCS OWS BUS 2 CUR	0 to 140	60	MAX
E.	M7047-411	DAS HI LEV MUX E HI	0 to 5	4.77	4.89
F.	M7051-411	DAS HI LEV MUX T HI	0 to 5	4.77	4.89
G.	G7008-432	POS-SAS WING 1 SEC 1	0 to 100	96.7	100.5
H.	G7009-432	POS-SAS WING 1 SEC 2	0 to 100	96.7	100.5
I.	G7010-432	POS-SAS WING 1 SEC 3	0 to 100	96.7	100.5
J.	G7011-433	POS-SAS WING 2 SEC 1	0 to 100	96.7	100.5
K.	G7012-433	POS-SAS WING 2 SEC 2	0 to 100	96.7	100.5
L.	G7013-433	POS-SAS WING 2 SEC 3	0 to 100	96.7	100.5
M.	M0159-509	AM BUS 1 CUR	0 to 100	5	40
N.	M0160-509	AM BUS 2 CUR	0 to 100	5	40
O.	M0155-513	AM BUS 1 V	15 to 35	27.7	30
P.	M0156-513	AM BUS 2 V	15 to 35	27.7	30
Q.	M7060-404	SAS FRNG EBW FU 1 V	0 to 5	4.3	5.0
R.	M7061-404	SAS FRNG EBW FU 2 V	0 to 5	4.3	5.0
S.	M7066-411	SAS WING SE EBW FU 1 V	0 to 5	4.3	5.0
T.	M7067-411	SAS WING SE EBW FU 2 V	0 to 5		

Figure 6.5a Typical D/TV Display for OWS Solar Array Deployment

SP803

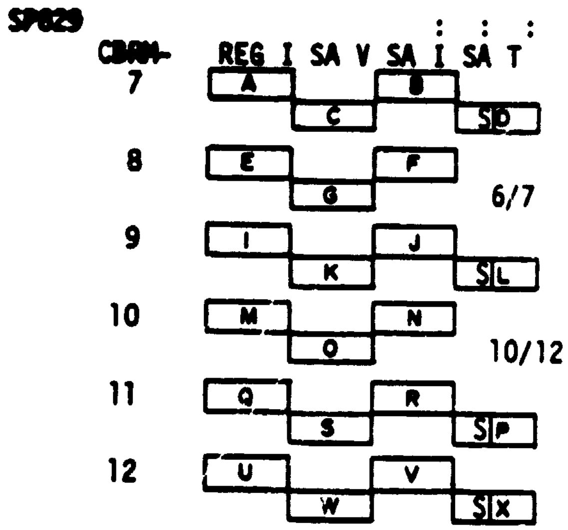
SOLAR ARRAY WING DEPLOYMENT

K0411	A	WING 1	SIG 1
K0412	B	WING 1	SIG 2
K0413	C	WING 2	SIG 1
K0414	D	WING 2	SIG 2
K0415	E	WING 3	SIG 1
K0416	F	WING 3	SIG 2
K0417	G	WING 4	SIG 1
K0418	H	WING 4	SIG 2

802

	MEAS.	MEAS. TITLE	LIMITS	REDLINE MIN	REDLINE MAX
A.	K411-710	ATM SA WING 1 SIG 1 DEPLOY & LOCK	0 or 28 V	-	-
B.	K412-710	ATM SA WING 1 SIG 2 DEPLOY & LOCK	0 or 28 V	-	-
C.	K413-711	ATM SA WING 2 SIG 1 DEPLOY & LOCK	0 or 28 V	-	-
D.	K414-711	ATM SA WING 2 SIG 2 DEPLOY & LOCK	0 or 28 V	-	-
E.	K415-712	ATM SA WING 3 SIG 1 DEPLOY & LOCK	0 or 28 V	-	-
F.	K416-712	ATM SA WING 3 SIG 2 DEPLOY & LOCK	0 or 28 V	-	-
G.	K417-713	ATM SA WING 4 SIG 1 DEPLOY & LOCK	0 or 28 V	-	-
H.	K418-713	ATM SA WING 4 SIG 2 DEPLOY & LOCK	0 or 28 V	-	-

Figure 6.5b Typical D/TV Display for ATM Solar Array Deployment



829

CBRM		MEAS.	MEAS. TITLE	LIMITS	REDLINE MIN	REDLINE MAX
7	A.	M102-702	REG I O/P	0 to 21A	0	10A
	B.	M042-702	SA I I/P to CBRM	0 to 21A	0	14A
	C.	M024-702	SA V I/P to CBRM	8.2 to 94.7V	25V	75V
	D.	C234-711	SA T(BACK)711A3	-65 to 110°C	-	-
		C235-711	SA T(FACE)711A3	-65 to 110°C	-	-
8	E.	M103-702	REG I O/P	0 to 21A	0	10A
	F.	M043-702	SA I I/P to CBRM	0 to 21A	0	14A
	G.	M025-702	SA V I/P to CBRM	8.2 to 94.7V	25V	75V
9	I.	M005-702	REG I O/P	0 to 21A	0	10A
	J.	M035-702	SA I I/P to CBRM	0 to 21A	0	14A
	K.	M017-702	SA V I/P to CBRM	8.2 to 94.7V	25V	75V
	L.	C347-712	SA T(BACK)712A2	-65 to 110°C	-	-
10	M.	M006-702	REG I O/P	0 to 21A	0	10A
	N.	M036-702	SA I I/P to CBRM	0 to 21A	0	14A
	O.	M018-702	SA V I/P to CBRM	8.2 to 94.7V	25V	75V
	P.	C238-712	SA T(BACK)712A3	-65 to 110°C	-	-
		C239-712	SA T(FACE)712A3	-65 to 110°C	-	-
11	Q.	M007-702	REG I O/P	0 to 21A	0	10A
	R.	M037-702	SA I I/P to CBRM	0 to 21A	0	14A
	S.	M019-702	SA V I/P to CBRM	8.2 to 94.7V	25V	75V
12	U.	M008-702	REG I O/P	0 to 21A	0	10A
	V.	M038-702	SA I I/P to CBRM	0 to 21A	0	14A
	W.	M020-702	SA V I/P to CBRM	8.2 to 94.7V	25V	75V
	X.	C240-712	SA T(BACK)712A5	-65 to 110°C	-	-

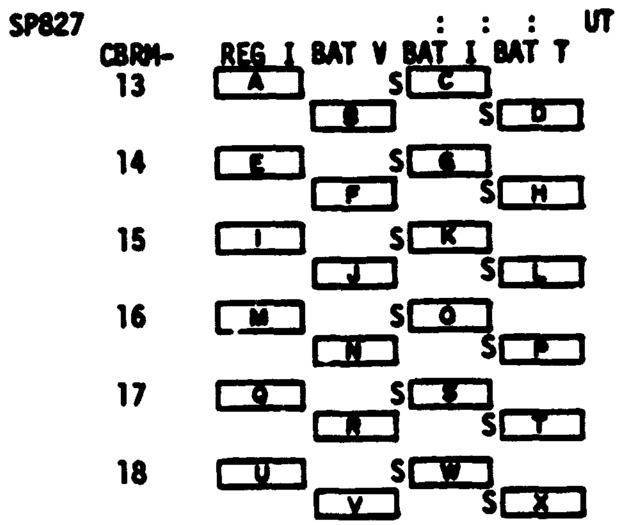
Figure 6.5c Typical D/TV Display for ATM Solar Array Performance

SP816 SAS GROUP	SAS VOLTS	SAS AMPS	PCG
			: : : UT
1	A	I	Q
2	B	J	R
3	C	K	S
4	D	L	T
5	E	M	U
6	F	N	V
7	G	O	W
8	H	P	X

816

	MEAS.	MEAS. TITLE		LIMITS	REDLINE MIN	REDLINE MAX
A.	M0101-S24	SAS GRP 1	V	0 TO 125	53	123
B.	M0102-S24	SAS GRP 2	V	0 TO 125	53	123
C.	M0103-S24	SAS GRP 3	V	0 TO 125	53	123
D.	M0104-S24	SAS GRP 4	V	0 TO 125	53	123
E.	M0105-S25	SAS GRP 5	V	0 TO 125	53	123
F.	M0106-S25	SAS GRP 6	V	0 TO 125	53	123
G.	M0107-S25	SAS GRP 7	V	0 TO 125	53	123
H.	M0108-S25	SAS GRP 8	V	0 TO 125	53	123
I.	M0109-S24	SAS GRP 1	CUR	0 TO 50	0	30
J.	M0110-S24	SAS GRP 2	CUR	0 TO 50	0	30
K.	M0111-S24	SAS GRP 3	CUR	0 TO 50	0	30
L.	M0112-S24	SAS GRP 4	CUR	0 TO 50	0	30
M.	M0113-S25	SAS GRP 5	CUR	0 TO 50	0	30
N.	M0114-S25	SAS GRP 6	CUR	0 TO 50	0	30
O.	M0115-S25	SAS GRP 7	CUR	0 TO 50	0	30
P.	M0116-S25	SAS GRP 8	CUR	0 TO 50	0	30
Q.	K0103-S24	SAS GRP 1	TO PCG 1-2	ONE = PCG 1	-	-
R.	K0104-S24	SAS GRP 2	TO PCG 2-3	ONE = PCG 2	-	-
S.	K0105-S24	SAS GRP 3	TO PCG 3-4	ONE = PCG 3	-	-
T.	K0106-S24	SAS GRP 4	TO PCG 4-1	ONE = PCG 4	-	-
U.	K0107-S25	SAS GRP 5	TO PCG 5-6	ONE = PCG 5	-	-
V.	K0108-S25	SAS GRP 6	TO PCG 6-7	ONE = PCG 6	-	-
W.	K0109-S25	SAS GRP 7	TO PCG 7-8	ONE = PCG 7	-	-
X.	K0110-S25	SAS GRP 8	TO PCG 8-5	ONE = PCG 8	-	-

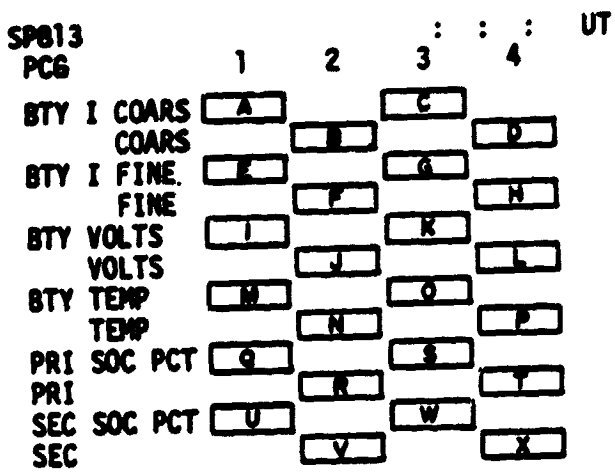
Figure 6.5d Typical D/TV Display for OWS Solar Array Performance



827

CBRM		MEAS.	MEAS. TITLE	LIMITS	REDLINE MIN	MAX
13	A.	M099-702	CBRM #13 O/P (CUR)	0 to 21A	0	10A
	B.	M607-702	BATTERY #13 (CUR)	-20 to +22A	-12A	+16A
	C.	M011-702	BATTERY #13 (VOLT)	15 to 41.3V	---	--
	D.	C022-702	BATTERY #13 (TEMP)	-20 to 55°C	0°C	35°C*
14	E.	M100-702	CBRM #14 O/P (CUR)	0 to 21A	0	10A
	F.	M608-702	BATTERY #14 (CUR)	-20 to +22A	-12A	-16A
	G.	M012-702	BATTERY #14 (VOLT)	15 to 41.3V	---	--
	H.	C023-702	BATTERY #14 (TEMP)	-20 to 55°C	0°C	35°C*
15	I.	M094-702	CBRM #15 O/P (CUR)	0 to 21A	0	10A
	J.	M602-702	BATTERY #15 (CUR)	-20 to +22A	-12A	+16A
	K.	M006-702	BATTERY #15 (VOLT)	15 to 41.3V	---	--
	L.	C017-702	BATTERY #15 (TEMP)	-20 to 55°C	0°C	35°C*
16	M.	M104-702	CBRM #16 O/P (CUR)	0 to 21A	0	10A
	N.	M612-702	BATTERY #16 (CUR)	-20 to +22A	-12A	+16A
	O.	M016-702	BATTERY #16 (VOLT)	15 to 41.3V	---	--
	P.	C027-702	BATTERY #16 (TEMP)	-20 to 55°C	0°C	35°C*
17	Q.	M105-702	CBRM #17 O/P (CUR)	0 to 21A	0	10A
	R.	M613-702	BATTERY #17 (CUR)	-20 to +22A	-12A	+16A
	S.	M017-702	BATTERY #17 (VOLT)	15 to 41.3V	---	--
	T.	C028-702	BATTERY #17 (TEMP)	-20 to 55°C	0°C	35°C*
18	U.	M106-702	CBRM #18 O/P (CUR)	0 to 21A	0	10A
	V.	M614-702	BATTERY #18 (CUR)	-20 to +22A	-12A	+16A
	W.	M018-702	BATTERY #18 (VOLT)	15 to 41.3V	---	--
	X.	C029-702	BATTERY #18 (TEMP)	-20 to 55°C	0°C	35°C*

Figure 6.5e Typical D/TV Display for CBRM Performance



813

MEAS.	MEAS. TITLE	LIMIT	REDLINE MIN	REDLINE MAX
A. M0141-S24	BAT 1 CUR	-50 to +50	-30	+40
B. M0142-S24	BAT 2 CUR	-50 to +50	-30	+40
C. M0143-S24	BAT 3 CUR	-50 to +50	-30	+40
D. M0144-S24	BAT 4 CUR	-50 to +50	-30	+40
E. M0171-S24	BAT 1 F CUR	-10 to +10	-5	+5
F. M0172-S24	BAT 2 F CUR	-10 to +10	-5	+5
G. M0173-S24	BAT 3 F CUR	-10 to +10	-5	+5
H. M0174-S24	BAT 4 F CUR	-10 to +10	-5	+5
I. M0133-S24	BAT 1 V	25 to 50	33	45.4
J. M0134-S24	BAT 2 V	25 to 50	33	45.4
K. M0135-S24	BAT 3 V	25 to 50	33	45.4
L. M0136-S24	BAT 4 V	25 to 50	33	45.4
M. C0101-S24	BAT 1 TEMP °F	-60 to +200	+40	+80
N. C0102-S24	BAT 2 TEMP °F	-60 to +200	+40	+80
O. C0103-S24	BAT 3 TEMP °F	-60 to +200	+40	+80
P. C0104-S24	BAT 4 TEMP °F	-60 to +200	+40	+80
Q. M0117-S24	BAT 1 PRI SOC	0 to 100	70% MIN	
R. M0118-S24	BAT 2 PRI SOC	0 to 100	70% MIN	
S. M0119-S24	BAT 3 PRI SOC	0 to 100	70% MIN	
T. M0120-S24	BAT 4 PRI SOC	0 to 100	70% MIN	
U. M0125-S24	BAT 1 SEC SOC	0 to 100	70% MIN	
V. M0126-S24	BAT 2 SEC SOC	0 to 100	70% MIN	
W. M0127-S24	BAT 3 SEC SOC	0 to 100	70% MIN	
X. M0128-S24	BAT 4 SEC SOC	0 to 100	70% MIN	

Figure 6.5f Typical D/TV Display for PCG Performance

SP831 : : : UT

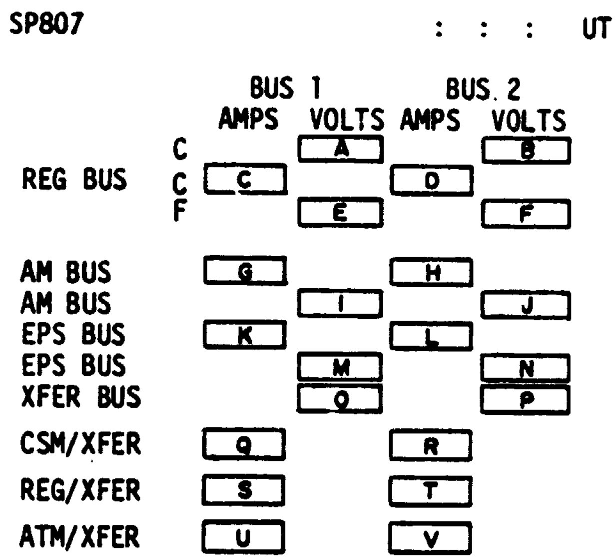
ELECTRICAL SYS

CURRENT 7D11	A	AMPS
CURRENT 7D11	B	AMPS
VOLTAGE 7D11	C	VOLTS
VOLTAGE 7D21	D	VOLTS
VOLTAGE 7D12	E	VOLTS
VOLTAGE 7D22	F	VOLTS
VOLTAGE 7D13	G	VOLTS
VOLTAGE 7D23	H	VOLTS
VOLTAGE 7D14	I	VOLTS
VOLTAGE 7D24	J	VOLTS
VOLTAGE 7D15	K	VOLTS
VOLTAGE 7D25	L	VOLTS
VOLTAGE 7D16	M	VOLTS
VOLTAGE 7D26	N	VOLTS
VOLTAGE 7D31	O	VOLTS
VOLTAGE 7D41	P	VOLTS
VOLTAGE 7D61	Q	VOLTS

SP831

	MEAS	MEASUREMENT NOMENCLATURE	MEAS RANGE	REDLINE MIN	MAX
A	[illegible]-702	CURRENT 7D11 LOAD BUS 1	0 to 300 A	0	70 A
B	[illegible]-702	CURRENT 7D21 LOAD BUS 2	0 to 300 A	0	70 A
C	[illegible]-702	VOLTAGE 7D11 LOAD BUS 1	24 to 32 V	28.3 V	30.5 V
D	[illegible]-702	VOLTAGE 7D21 LOAD BUS 2	24 to 32 V	28.3 V	30.5 V
E	[illegible]-702	VOLTAGE 7D12 AAPCS BUS 1	24 to 32 V	26 V	30.5 V
F	[illegible]-702	VOLTAGE 7D22 AAPCS BUS 2	24 to 32 V	26 V	30.5 V
G	[illegible]-702	VOLTAGE 7D13 CAD BUS 1	24 to 32 V	26 V	30.5 V
H	[illegible]-702	VOLTAGE 7D23 CAD BUS 2	24 to 32 V	26 V	30.5 V
I	[illegible]-702	VOLTAGE 7D14 CANIST THERMAL BUS 1	24 to 32 V	26 V	30.5 V
J	[illegible]-702	VOLTAGE 7D24 CANIST THERMAL BUS 2	24 to 32 V	26 V	30.5 V
K	[illegible]-702	VOLTAGE 7D15 TH BUS 1	24 to 32 V	26 V	30.5 V
L	[illegible]-702	VOLTAGE 7D25 TH BUS 2	24 to 32 V	26 V	30.5 V
M	[illegible]-702	VOLTAGE 7D16 TV BUS 1	24 to 32 V	26 V	30.5 V
N	[illegible]-702	VOLTAGE 7D26 TV BUS 2	24 to 32 V	26 V	30.5 V
O	[illegible]-702	VOLTAGE 7D31 CONT. DEST. BUS 1	24 to 32 V	26 V	30.5 V
P	[illegible]-702	VOLTAGE 7D41 CONT. DEST. BUS 2	24 to 32 V	26 V	30.5 V
Q	[illegible]-702	VOLTAGE 7D61 (5 V PWR SUPPLY)	0 to 6 V	4.9 V	5.0 V

Figure 6.5g Typical D/TV Display for ATM Bus Performance



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	MEAS.	MEAS. TITLE		LIMITS	REDLINE MIN	REDLINE MAX
A.	M0153-513	REG BUS 1	V.	15 TO 35	28.1	30
B.	M0154-513	REG BUS 2	V.	15 TO 35	28.1	30
C.	M0163-509	REG BUS 1	CUR	0 TO 200	20	75
D.	M0164-509	REG BUS 2	CUR	0 TO 200	20	75
E.	M0161-513	REG BUS 1	F.V.	25 TO 32	28.1	30
F.	M0162-513	REG BUS 1	F.V.	25 TO 32	28.1	30
G.	M0159-509	AM BUS 1	CUR	0 TO 100	5	40
H.	M0160-509	AM BUS 2	CUR	0 TO 100	5	40
I.	M0155-513	AM BUS 1	V.	15 TO 35	27.7	30
J.	M0156-513	AM BUS 2	V.	15 TO 35	27.7	30
K.	M0169-538	EPS BUS 1	CUR	0 TO 50	3	6
L.	M0170-538	EPS BUS 2	CUR	0 TO 50	3	6
M.	M0151-513	EPS BUS 1	V.	15 TO 35	25.5	30
N.	M0152-513	EPS BUS 2	V.	15 TO 35	25.5	30
O.	M0149-513	XFER BUS 1	V.	15 TO 35	28	30
P.	M0150-513	XFER BUS 2	V.	15 TO 35	28	30
Q.	M0165-509	XFER/CSM 1	CUR	0 TO 100	10	35
R.	M0166-509	XFER/CSM 2	CUR	0 TO 100	10	35
S.	M0167-509	REG/XFER 1	CUR	-100 TO +100	-20	20
T.	M0168-509	REG/XFER 2	CUR	-100 TO +100	-20	20
U.	M0157-509	ATM/XFER 1	CUR	-100 TO +100	+10	40
V.	M0158-509	ATM/XFER 2	CUR	-100 TO +100	+10	40

Figure 6.5h Typical D/TV Display for Skylab Main Bus Performance

Table 6.I HOSC EPS Console Log for SL-1 through SL-4

DAY:GMT	EVENTS/SL-1
01:17:30:00	SL-1 LIFT - OFF (FIRST MOTION)
17:31:03	OWS SAS WING 2 BEAM FAIRING SEPARATION
17:34:48	MDA VENT VALVES CLOSED
17:39:51	S-II/PAYLOAD SEPARATION
17:39:54	AM SEQUENTIAL BUS ACTIVATION
17:45:21	PS JETTISON
17:45:34	AM DEPLOY BUS ACTIVATION
17:46:49	INITIATE ATM DEPLOYMENT
17:46:53	DISCONE ANTENNA 2 DEPLOYED
17:46:54	DISCONE ANTENNA 1 DEPLOYED
17:48:56	ATM DEPLOYED AND LOCKED
17:54:49	INITIATE ATM SAS DEPLOYMENT
19:04:27	BACK-UP RS RAD SHIELD JETTISON CMD (AM DCS)
19:08:22	BACK-UP OWS SAS BEAM COMMANDS (AM DCS)
19:20:56	BACK-UP OWS SAS WING COMMANDS (AM DCS)
19:27:23	PARALLEL ATM/AM POWER SYSTEMS (BUS 1)
19:27:38	PARALLEL ATM/AM POWER SYSTEM (BUS 2)
19:28:04	PCG 1 OFF
19:28:14	PCG 2 OFF
19:29:05	PCG 3 OFF
19:29:13	PCG 4 OFF
19:29:24	PCG 5 OFF
19:29:36	PCG 6 OFF
19:29:48	PCG 7 OFF
19:30:06	PCG 8 OFF
20:12:30	BACK-UP METEOROID SHIELD JETT CMD
20:33:56	AM DEPLOY BUSES OFF
23:23:53	PCG 1 ON
23:24:07	BATT 1 OFF (AM)
23:24:25	PCG 2 ON
23:24:41	BATT 2 OFF
23:25:06	PCG 3 ON
23:25:21	BATT 3 OFF
23:27:56	PCG 8 ON
23:28:18	BATT 8 OFF
23:28:34	PCG 7 ON
23:28:52	BATT 7 OFF
02:00:15:07	BATT 1-8 SOC's: 59.9, 61.2, 62.3, 59.7, 65.3, 73, 62.3, 62.6
05:22:30	PCG 5 ON
06:22:00	BATT 5 OFF. VEHICLE MANEUVERED TO 90°
08:10:00	VEHICLE MANEUVERED TO 45°
10:30:00	BACK TO SI

DAY:GMT	EVENTS/SL-1
15:18:18	PCG 6 ON
15:18:37	BATT 6 OFF (SOC 76.2%)
23:16:28	PCG 6 OFF
23:16:51	BATT 6 ON
23:17:18	SAS 5 TO PCG 6
03:01:07:01	BATT 6 OFF (SOC 60.5%)
01:58:00	BATT 6 ON
02:40:00	BATT 6 OFF BATT 6 cycled in attempt to recharge
03:02:25	BATT 6 ON
04:13:36	BATT 6 OFF
06:17:48	BATT 6 ON
07:20:11	BATT 6 OFF
09:27:49	BATT 6 ON
09:28:25	CHG 1 BY-PASS
09:28:36	CHG 2 BY-PASS
09:28:46	CHG 3 BY-PASS
09:28:55	CHG 4 BY-PASS
09:29:19	CHG 8 BY-PASS
09:29:55	CHG 7 BY-PASS
10:26:35	BATT 6 OFF
11:03:59	BATT 6 ON
11:09:00	SAS 2 TO PCG 3/SAS 7 TO PCG 8
12:01:38	BATT 6 OFF
13:02:42	BATT 6 ON
13:45:00	BATT 6 OFF
14:37:00	BATT 6 ON
15:21:06	BATT 6 OFF
15:32:15	BATT 6 ON
16:26:01	BATT 6 OFF
17:40:31	BATT 6 ON
18:05:31	BATT 6 OFF
19:01:00	VEHICLE AT 45° PITCH ATTITUDE
19:28:07	CBRM 5 REG OFF (BATT NOT CHARGING DUE TO ATTITUDE)
19:28:26	CBRM 6 REG OFF (BATT NOT CHARGING DUE TO ATTITUDE)
19:42:34	CBRM 5 REG ON
19:42:51	CBRM 6 REG ON
20:23:20	BATT 6 ON
20:46:00	VEHICLE PITCHED TO 50°
21:16:13	BATT 6 OFF
04:04:00:00	VEHICLE DRIFTED TO 55° TO 60° (5° CORRECTION INITIATED)
05:00:10	CBRM 5 REG OFF
05:00:21	CBRM 6 REG OFF
05:33:42	CBRM 5 REG ON
05:33:54	CBRM 6 REG ON

DAY:GMT	EVENTS/SL-1
06:42:21	CBRM 5 REG OFF
06:42:29	CBRM 6 REG OFF
07:10:16	CBRM 5 REG ON
07:10:25	CBRM 6 REG ON
07:30:00	ATTITUDE IS 50^{o} PITCH, 13^{o}Y, 01^{o}R
08:44:04	CBRM 5 REG OFF
09:04:03	CBRM 5 REG ON
14:08:10	CBRM 5 REG OFF
14:08:25	CBRM 6 REG OFF
14:35:27	CBRM 5 REG ON
14:35:41	CBRM 6 REG ON
15:45:33	CBRM 5 REG OFF
15:45:45	CBRM 6 REG OFF CBRM's 5 & 6 were cycled on and off throughout 45^{o} pitch att. (load management). (145:08:13 stopped)
16:12:27	CBRM 5 REG ON
16:12:40	CBRM 6 REG ON
05:00:27:00	MANEUVERED BACK TO SI
11:21:56	PCG 6 ON
06:05:58:00	MANEUVERED TO 50^{o} PITCH-UP
07:19:13	CBRM 14 REG OFF
07:36:50	CBRM 14 REG ON
07:20:10:00	AUTO SWITCH OVER IN COOLANT LOOP (TO SEC)
01:15:00	2ND AUTO SWITCH OVER TO SECONDARY
01:15:36	AM PRI COOLANT INV 1 OFF
01:15:47	AM PRI COOLANT INV 1 ON
01:16:23	CMD AM COOLANT LOOP TO PRI
01:16:44	AM SEC INV 1 OFF
01:43:00	AM COOLANT LOOP AUTO SWITCH TO SECONDARY
03:20:53	PRI INV 1 OFF
03:21:17	SEC INV 1 ON
03:21:56	SEC AUTO SWITCH-OVER ENABLED
08:13:49	SAS 5 TO PCG 5
08:14:36	SAS 7 TO PCG 7
08:14:56	CHG 7 NORM
08:15:00	CHG 8 NORM
08:27:49	PCG 7 OFF
08:28:00	SAS 6 TO PCG 7
08:28:39	BATT 7 ON
08:29:41	PCG 5 OFF
08:29:55	SAS 8 TO PCG 5
08:30:09	BATT 5 ON
09:12:50	BATT 7 OFF
09:13:12	BATT 5 OFF
09:52:00	BATT 5 & 7 ON
10:09:31	BATT 5 OFF
10:11:40	BATT 5 ON
10:47:50	BATT 7 OFF

DAY:GMT	EVENTS/SL-1	
10:48:00	BATT 5 OFF	
11:46:12	BATT 7 ON	
11:47:00	BATT 5 ON	
12:27:42	BATT 5 OFF & 7 OFF	
12:29:00	CHG 1, 2, 3, 4, TO NORM	
13:16:00	BATT 5 ON & 7 ON	
13:18:00	BATT 3 ON	
13:19:00	BATT 3 OFF	
14:04:00	BATT 5 & 7 OFF	
14:50:00	BATT 5 & 7 ON	
15:00:00	FORMAL REQUEST TO PUT ALL CHRGS EXCEPT 6&7 TO BY-PASS TO PREVENT CHGR ON/OFF OSCILLATIONS DUE TO LOW SAS VOLTAGE	
15:43:00	BATT 5 & 7 OFF	
16:26:00	BATT 7 ON	
16:52:00	BATT 7 OFF	
17:59:00	BATT 7 ON	
18:00:00	SAS 8 & 5 VOLTAGE BEGAN OSCILLATING BETWEEN 48 AND 68 V. CHGR 5 ON/OFF CYCLING	
18:32:00	BATT 7 OFF	
20:47:00	BATT 7 ON	
23:08:00	BATT 7 OFF	
23:54:00	BATT 7 ON	
08:00:44:00	BATT 7 OFF	
02:49:00	CALLED EGIL BACK-ROOM TO PUT CHARGERS TO BY-PASS	
04:25:00	BATT 7 ON	
05:45:00	CALLED EGIL BACK ROOM AGAIN TO PUT CHARGER IN BY-PASS	
05:55:00	CHG 1, 3, 4 TO BY-PASS	
15:40:00	BATT 7 ON	
16:08:00	BATT 7 OFF	
17:20:00	BATT 7 ON THEN OFF	
17:31:00	BATT 7 ON	
17:40:00	BATT 7 OFF	
18:31:00	BATT 7 ON	
18:43:00	PCG 3 & 5 ON	
19:25:50	BATT 7 OFF	
20:05:40	BATT 7 ON	
20:52:16	BATT 7 OFF	
21:36:00	BATT 7 ON	(Main reason for charging/discharging
22:28:26	BATT 7 OFF	batt. 7 is to provide heat to AM
23:11:00	BATT 7 ON	coolant loop.)
09:00:00:48	BATT 7 OFF	
00:19:40	BATT 7 ON	
01:36:00	BATT 7 OFF	

DAY:GMT	EVENTS/SL-1
01:58:00	BATT 7 ON
03:04:14	BATT 7 OFF (SOC 70.8%)
03:36:30	BATT 7 ON
08:36:00	PCG 5 OFF/BATT 5 ON
08:37:00	CHG 5 NORM (FINE BATT 5-0.17 AMP)
11:10:00	BATT 5 OFF
13:18:00	ATTITUDE IS 40^{o} UP, 0^{o} YAW, 0^{o} ROLL
13:32:00	BATT 5 ON
13:32:30	BAS 5 & 8 VOLTAGES BEGAN OSCILLATING
13:39:00	BATT 5 OFF
15:16:00	SENT AR TO EGIL TO HAVE CHG 5 TO BY-PASS (TELECON ALSO)
15:17:00	CHG 5 TO BY-PASS & PCG 5 ON
16:34:00	BATT 7 IN ENERGY BALANCE AT APPROX. 50 WATTS OF SAS POWER
18:00:00	BATT 5 ON/CHG 5 NORM/PCG 5 OFF
18:42:00	SAS 8 & 5 START OSCILLATING (SAS 8 & 5 TO PCG 5)
18:46:00	AR TO EGIL TO TURN BATT 5 OFF, PCG 5 ON, CHG TO BY-PASS
22:29:50	BATT 7 ON
10:02:17:25	BATT 7 OFF
02:54:23	BATT 7 ON
03:20:00	CBRM 15 SAS CONTACTOR FAILED OPEN
04:04:10	BATT 7 OFF
04:31:00	BATT 7 ON
05:37:11	BATT 7 OFF
06:18:00	BATT 7 ON
07:06:30	BATT 7 OFF
07:53:40	BATT 7 ON
08:44:58	BATT 7 OFF
09:24:32	BATT 7 ON
10:26:32	BATT 7 OFF
10:32:00	BATT 7 ON
11:58:33	BATT 7 OFF
12:43:48	BATT 7 ON
15:34:00	PRESENTLY AT 46^{o} PITCH (WILL GO TO 48^{o})
21:16:58	BATT 7 OFF
21:54:22	CHG 7 - BY PASS/PCG 7 ON
23:20:00	MAR SUBMITTED TO EGIL TO USE FOLLOWING PROCEDURE WHEN RECONFIG. PCG'S: o CHG TO NORM o BATT ON o PCG ON o BATT OFF o CHG - BY-PASS
21:40:00	MANEUVER TO -65^{o} PITCH/HOLD FOR 2 REV'S/THEN TO -45^{o} PITCH/HOLD FOR 5 REV'S/THEN TO 50^{o} PITCH

DAY:GMT	EVENTS/SL-1
11:01:04:00	PCG 7 OFF, CHG - NORM, BATT 7 ON
07:10:00	ATTITUDE CHANGE TO - 51°
09:45:00	BATT 7 OFF
10:32:00	BATT 7 ON
10:43:00	AT - 45° ATT GOING TO - 50° ATT
11:15:00	BATT 7 OFF
12:01:00	BATT 7 ON
12:51:00	BATT 7 OFF
13:32:00	BATT 7 ON
13:47:00	ATT - 50°
13:47:00	SAS 6 & 7: NOT ENOUGH SAS PWR TO CHG BATT.
13:59:50	BATT 7 OFF
15:10:00	BATT 7 ON - NOT ENOUGH SAS PWR TO CHG, BUT LEFT ON FOR COOLANT LOOP HEAT
17:50:23	BATT 7 OFF
18:12:00	BATT 7 ON
18:17:00	PITCHED TO 54° ATT
18:58:00	BATT 7 OFF
19:50:00	MANEUVERED TO - 40° PITCH ATT, 0° ROLL
20:10:00	BATT 7 ON
21:22:56	BATT 7 OFF
21:23:06	PCG 7 ON
22:40:00	SAS 6 & 7 VOLTAGE OSCILLATING - CALLED FOMR TO HAVE EGIL SWITCH TO BY-PASS
23:18:18	CHG 7 - BY-PASS
12:04:51:00	CBRM's 4, 6, 7, 11, 12, 15, AUTO SWITCH OFF, GND COMMANDED 4, 6, 7, 11 AND 12 ON. ATTEMPTS TO RE-CONNECT 15 FAILED
07:50:00	CBRM 15 BACK - ON
08:09:00	CBRM 15 NOT CHARGING

	EVENTS/SL-2
13:00:00	SL-2 LIFT-OFF
14:29:07	BATT 7 ON, CHG 5-NORM
17:55:16	PCG 5 OFF/BATT 5 ON/ CHG 5 - NORM
17:57:07	TRACKING LIGHTS ON
18:43:28	BATT 5 OFF
20:41:14	BATT 7 OFF
21:03:00	FLY-AROUND OF OWS
21:07:52	CHG 5-BY-PASS
21:08:04	CHG 7-BY-PASS
21:15:00	SOFT - DOCK - A OK
21:58:00	SAS 2-PCG 2, SAS 6-PCG 6, SAS 8-PCG 8

DAY:GMT	EVENTS/SL-2
21:58:56	DOCK LITES Z AXIS OFF
21:59:09	DOCK LITES Y AXIS OFF
22:36:32	PCG 1 OFF/BATT 1 ON
22:37:02	CHG 1 NORM
22:37:17	PCG 2 OFF/BATT 2 ON
22:37:51	PCG 3 OFF/BATT 3 ON/CHG 3-NORM
22:38:00	PCG 4 OFF/BATT 4 ON/CHG 4-NORM
22:39:40	BATT 5 ON/CHG 5-NORM
22:40:13	PCG 6 OFF/BATT 6 ON
22:40:41	BATT 7 ON/CHG-NORM
22:41:18	PCG 8 OFF/BATT 8 ON
23:29:00	UNDOCKING
13:00:14:57	DOCK LITES Z AXIS ON
00:15:06	DOCK LITES X AXIS ON
00:23:00	UNABLE TO DEPLOY OWS SAS WING (EVA)
03:53:20	DOCK LITES OFF
06:28:17	BATT 1 OFF/CHG 1-BY-PASS/PCG 1 ON
06:28:34	PCG 2 ON/BATT 2 ON/BATT 2 OFF/CHG 2-BY-PASS
06:29:44	PCG 3 ON/BATT 3 OFF/CHG 3-BY-PASS
06:30:13	PCG 4 ON/CHG 4-BY-PASS/BATT 4 OFF
06:30:43	PCG 5 ON/BATT 5 OFF/CHG 5-BY-PASS
06:31:00	PCG 6 ON/BATT 6 OFF/CHG 6-BY-PASS
06:33:11	PCG 8 ON/BATT 8 OFF/CHG 8-BY-PASS
06:33:11	SAS 6 TO PCG 7
06:33:31	BATT 7 OFF
07:26:48	BATT 7 ON
09:53:57	BATT 7 OFF
10:45:00	BATT 7 ON
11:25:41	BATT 7 OFF
13:00:00	BATT 7 ON
13:04:17	BATT 7 OFF
13:55:51	BATT 7 ON
14:50:33	BATT 7 OFF
15:26:00	BATT 7 ON
15:49:17	BATT 7 OFF
16:23:00	CREW ENTERED MDA
16:30:00	MDA ACTIVATION START
16:30:00	CSM DE-ACTIVATION START
16:46:00	BATT 7 ON
16:55:00	STS ENTRY
17:02:00	SEQUENTIAL BUSES OFF
17:04:00	STS CB PANELS CONFIGURED
17:09:00	CM/MDA UMBILICALS CONNECTED
17:26:00	C&W SYSTEM ACTIVATED
17:30:00	SPG TRANSFERRED TO CSM

DAY:GMT	EVENTS/SL-2
18:35:00	OWS ENTRY
18:40:00	C&W TESTS
19:30:00	CONDENSATE DUMP HTR-SEC-DID NOT SHOW TEMP. LITE ON
14:01:30:00	PARASOL DEPLOYMENT
02:40:00	#8 A-H INTEGRATOR C/B OPEN ACCIDENTLY BY CREW (FOOT SLIPPED UNDER GUARD) BOTH PRI/ SEC AHI RESET TO 0%.
04:17:31	PRI COOLANT LOOP INV 1 ON
22:46:00	20 AMP SPIKE REPORTED ON AM BUS 1 (AR 78) - FOUND TO BE CREW 10 SEC ACTIVATION OF MOLE SIEVE HEATERS
15:22:34:00	CREW STATED THEY TURNED ON MOLE SIEVE BED HTRS TO OBSERVE TEMP. (AR 78)
16:01:44:36	SEC COOLANT LOOP COMMANDED ON. CREW
03:25:00	REPORTED SEC INV 1 C/B OPENED AND THEY TURNED INV 2 PUMP B ON
03:29:33	DCS CMD - SEC INV 3 PUMP C ON FOR REDUNDANT BUS POWER
17:19:00:00	EREP #1
22:13:00	ATM EXPERIENCING ELECT. DIFFICULTIES. AUTO CUT-OFF EXPERIENCED AT DOD s MUCH LOWER THAN EXPECTED (APPROX. 50%). THIS KICKED OFF BATT 6, 7, 8, & 16. IN ADDITION REG 3, 6, 7, 8, & 16 KICKED OFF AT SR. THIS WAS NOT DISCOVERED UNTIL GOLDSTONE PASS (22:39) AT WHICH TIME THESE BATT WERE NOT CHARGING. APPROXIMATELY HALF WAY THRU DAYLIGHT CYCLE. CBRM 6, 7, 8, 16 WERE TURNED BACK ON. BUT CBRM #3 WOULD NOT COME ON. OFF LOADING WAS MADE INCLUDING SEC COOLANT LOOP
23:50:00	ALL CBRM "ON" SWITCH ATTEMPTED - NO JOY ON REG'S 3 & 15. CBRM 3 SAS CONTACTOR IS CLOSED BUT REG NOT OUTPUTING.
18:00:18:00	SEC LOOP BACK ON
20:03:07:00	WHEN WASTE MGMT HTR TURNED OFF, CREW REPORTED C&W ALARM ON OWS BUS 1 & 2 LOW. CHECKED AND FOUND OWS BUS 1 FEEDER #2 C/B OPEN.
03:43:00	OWS BUS LOW VOLT SENSE C/B FOUND OPEN (BUS 1 & 2)
22:05:02:36	BATT 7 ON
05:08:38	PCG 7 ON
05:51:00	BATT 5 ON
05:52:20	PCG 5 ON/CHG 5 - NORM
17:44:00	BATT 7 AT 100% SOC
07:40:00	SAS 5 VOLTS OSCILLATING (LASTED 5 MIN)

DAY:GMT	EVENTS/SL-2
08:21:00	SAS 5 VOLTS OSCILLATING FROM 34% TO 52% FULL SCALE (43-65V). BATT CHG CURRENT ALSO OSCILLATING (0-1a) FOR 2 1/2 MIN (SUNSET)
12:17:49	BATT 7 OFF
12:17:58	SAS 6 TO PCG 6
12:18:07	BATT 6 ON
12:18:18	CHG 6 - NORM
12:18:30	CHG 7 - BY-PASS
12:32:23	SAG 7 TO PCG 8/BATT 8 ON/CHG NORM
13:59:02	BATT 8 OFF
17:05:00	EREP PASS
18:57:00	CREW PERFORMED OWS BUS C&W TROUBLE SHOOTING - "TRULY AN UNEXPLAINED ANOMALY"- FLT DIR TO EGIL.
23:03:40:00	NOTICED SAS 5 OSCILLATIONS AT END OF MADRID PASS - 15 MIN LATER AT GWM, OSCILLATIONS HAD STOPPED. BATT CHG OK
04:17:00	GWM LOS - SAS 7 VOLT OSCILLATING (TO PCG 8) BATT 8 IS ON
05:20:00	BATT 5 OFF/CHG - BY-PASS
11:48:54	BATT 8 OFF/CHG - BY-PASS
12:10:00	BATT 5 & 7 - 100% SOC, BATT 6 - 100% PRI 95% SEC
15:02:00	MSFC REQUEST IF OK TO CYCLE TACS C/B ON & OFF ON PNL 202 TO INHIBIT
18:24:00	BATT 6 SEC A-H INTEG AT 100%
21:00:00	VERIFIED BATT 6 OFF (NO DATA) CHG BY-PASS
24:20:55:18	SAS 7 TO PCG 7/BATT 7 ON/CHG 7-NORM
20:55:47	SAS 6 TO PCG 7/BATT 6 ON/CHG 6-NORM
20:57:21	SAS 5 TO PCG 5/BATT 6 ON
25:02:10:20	BATT 6 & 7 OFF
03:54:25	SAS 5 TO PCG 5/SAS 6 TO PCG 6
03:55:07	CHG 6 TO BY-PASS/CHG 7 TO BY-PASS
15:48:46	BATT 6, 7, 8 ON
15:49:00	CHG 1, 2, 3, 4, 5, 6, 7, 8 - NORM
15:50:00	PCG 1, 2, 3, 4, 5, 6, 7, 8 - OFF
15:51:00	BATT 1 THRU 8 DISCHG LIMIT - INHIBIT
15:53:40	PCG 8 TO REG BUS 1
18:03:00	OWS SAS OUT AT AOS
18:32:00	PCG 1 THRU 8 ON
21:49:00	PCG 1 & 2 OFF/REG 8 TO BUS 1
23:26:00	REG 2 POT ADJUSTED CW 15°
26:00:25:00	SAS WING AT 100% DPLYMT - HURRAH!!
01:09:00	BACK TO SI

DAY:GMT	EVENTS/SL-2
02:40:00	PCG 8 BACK TO REG 2
02:46:00	CREW TOLD TO ADJUST REG 1 TO EQUAL REG 2 CURRENT
06:08:40	PCG 1-8 DISCHG LIMIT - AUTO
27:03:27:00	CREW TO GIVE EPS PANEL STATUS TOMMORROW
14:23:00	CREW ADJUSTED REG 2 COARSE POT CW UNTIL REG BUS CURRENTS EQUAL REG 1 - 37.7 amp REG 1 - 28.68 V REG 2 - 34.5 amp REG 2 - 28.73 V (2ND ADJUSTMENT)
15:02:00	EREP PASS #6 - REV 374 ORBIT 234 AVG LOAD - 2300 WATTS MAX DOD - 11%
28:14:19:00	EREP PASS #7 - REV 389 ORBIT 249 AVG LOAD - 2400 WATTS
29:05:01:00	BATT 8 SOC = 100%
13:10:00	PRESENT OCV 29.0. EGIL WANT CREW TO ADJUST TO 29.2. OCV
13:44:00	CREW ADJUSTED POTS TO 29.2 OCV.
15:12:00	EREP PASS #8 REV 404 ORBIT 265 AVG LOAD - 2300 WATTS MAX DOD - 23%
30:12:56:00	EREP PASS #9 REV 417 ORBIT 279 AVG LOAD - 2550 WATTS MAX DOD - 28%
31:13:46:00	EREP PASS #10 REV 432 ORBIT 295 MAX DOD - 31% AVG LOAD - 2500
32:03:01:00	CYCLING 17 AMP UNEXPLAINED LOAD WAS REPORTED CYCLING ON/OFF. WAS FIRST SEEN OVER MAD APPROX 02:00. SEEN AGAIN OVER CRO & HSK. CREW CHECKED VARIOUS SWITCHES, ALL OK
14:40:00	EREP PASS #11, REV 446, ORBIT 311, AVG LOAD - 2550, MAX DOD - 40%
17:49:00	XFERING CURRENT TO CSM. AT AOS: XFER/CSM BUS 1 = 26.2 a 2 = 15.5 a
17:54:00	CHG MODE 8 - TEMP LIMIT } SUSPECT DATA DROP
17:56:00	CHG MODE 8 - NORM
33:05:00:00	EGIL REPORTED CREW UNEVENLY SET REG POTS AFTER CSM XFER: REG 1 = 29.0 OCV REG 2 = 29.2 OCV NO CHANGE TO BE MADE AT THIS TIME
08:50:00	CREW TOLD EREP PASS TENTATIVELY PLANNED FOR DOY 169
35:19:41:00	CREW INSTRUCTED TO ADJUST BUS 1 POT 30° CW AND BUS 2 POT 20° CW. RESULT: REG BUS 1 OCV 29.35 BUS 2-29.42, WAS: REG BUS 1 OCV 29.03, BUS 2-29.16
36:19:10:00	FLT DIR/EGIL DISCUSSION TO ADJUST REG BUS OCV'S TO 29.5 FOLLOWING EVA FOR ORBIT STORAGE

DAY:GMT	EVENTS/SL-2
37:10:46:00	EVA
11:16:00	CREW HAMMERED ON CBRM 15-WORKED; CHG TURNED ON. HOW ABOUT THAT!!
19:55:00	CREW INSTRUCTED TO ADJUST REG BUS 1 POT 15° CW. INITIAL ADJUSTMENT VIA TM SHOWED TOO MUCH. CREW INSTRUCTED TO TURN BUS 1 POT 5° CCW. RESULTANT OCV BUS 1-29.5 BUS 2-29.5
20:30:00	ALL CONSOLE OPERATORS REVIEW "PROFESSIONAL OUTSIDE UNDERHANDED NATURAL DISCREPANCY EMISSION REVERSER (POUNDER)"
38:12:04:00	CREW CHECKED MDA PORT HTR C/B - OPEN - TEST OF CKT OK.
13:30:00	DISCUSSION CONCERNING BATT CNTL C/B BETWEEN EGIL & FDIR "EVERYTHING WILL BE DONE TO ASSURE THAT C/B PANELS ARE LEFT IN PROPER CONFIG. DURING DE-ACT., INCLUDING BATT CNTL C/B".
16:23:00	EGIL/F-DIR DISCUSSION - "EGIL CANNOT CONFIRM BATT CNTL C/B ARE CLOSED."
39:03:20:00	AT AOS LOOKS LIKE CSM TRANSFER TO INTERNAL PWR COMPLETE.
04:25:00	ADJUST REG BUS 2 FOR 5 AMPS. COMPLETE-OCV AT LOW LOAD TURNED OUT TO BE 29.4 ON EACH BUS.
40:08:55:00	CSM/SWS SEPARATION

	EVENTS/SL-3
76:11:08	SL-3 LIFT OFF
76:14:22	TRACKING LTS ON
76:18:27	DOCKING LTS ON Z AXIS LTS COMB OFF @ 10:15
76:19:00	DOCKING
76:22:43	S.P.G. - CSM
76:22:48	SIEVE B SEC FAN PROB.
77:13:35	SIEVE A FAN TO SEC & SIEVE B FAN TO PRI
77:19:20	CSM MN A&B C&W ALARM CREW REPORT - ALSO 20 A SPIKES MN A
79:10:33	Δ BETWEEN BATT #5 PSOC & SSOC
82:17:35	EREP #1
83:03:20	ATM TV BUS 2 SHORT. SHORT IN POWER XFER DISTRIBUTOR. OPERATION IS ON ATM TV BUS 1.
83:03:40	BAT 6&8 NOT 100%
83:16:27	EREP #2

DAY:GMT	EVENTS/SL-3
84:14:23	EREP #3
84:15:59	#6 DISCHG. LIMIT - INHIBIT
84:16:07	EREP #4
86:02:26	REG #1&2 ADJ - #1-29, 1 & #2-29.0
86:23:41	REG #2 ADJ - 29.2
87:13;49	POSSIBLE SIEVE FAN-SWITCHING
87:15:14	EREP #5
87:22:55	SIEVE B FAN T/S
87:23:13	SIEVE B FAN REPLACED - NEW FAN DID NOT WORK
88	CREW REPORTED MOLE SIEVE A&B HEAT EXCHANGER TEMPS READ LOW - TELEMETRY MEASUREMENTS ARE OK
88:13:07	EREP #6
88:13:15	#6 DISCHG LIMIT - INHIBIT
88:18:53	#6 DISCHG LIMIT - AUTO
89	CREW REPORTED CBRM #16 WOULD NOT TURN OFF FROM THE C&D PANEL
90:14:50	EREP #7
91:02:07	EREP #8
91:14:07	EREP #9
93	ATM BAT 7 CAP TEST = 12.1 AH
95:17:03	REG 1 & 2 ADJ #1-28.9 & #2-28.8
95:17:03	CSM ON XFER BUSES
97:18:54	REG #2 & FINE #6 & 7 ADJ 100 CCW(AFTER #1-28.9, #2-28.9)
98:07:55	ATM C&D PANEL BATT CHARGE ALERT LIGHT ON & FLAG BARBER POLE - PROBABLE CAUSE IS INTERMITTENT SHORT IN POWER TRANSFER DISTRIBUTOR
98:14:53	BAT #6 AMP HR. READING REACHED 100%. AFTER A PERIOD OF FAILING TO REACH 100% (TURN AROUND ERROR)
99:00:47	SIEVE A BED BAKEOUT
100:01:02	MDA LT PROB. AFT 2&4 LTS NOT WORKING
100:13:30	SEC CLNT PUMP C/B PROB.
101:18:37	#7 FINE ADJ - WAS TO BE 10°CW BUT WAS TURNED CCW
102:15:54	ATM BAT #18 CAP TEST - 13.1 AH
102:17:31	ATM BAT #10 CAP TEST - 12.4 AH
102:18:30	AM PRI CLNT LOOP SHUT-DWN
102:20:38	#7 FINE ADJ-.6 TO .7 AMP INCR.
103:12:52	REG #1& #2 ADJ FOR EVA: REG 1-20° CW; REG 2-30°CW(AFTER #1.29, 1 #2-29.1)
103:16:24	EVA CMG INSTALLATION
103:21:21	ERRATIC BEHAVIOR OF SECONDARY TIME REFERENCE SYSTEM REPORTED BY CREW

DAY:GMT	EVENTS/SL-3
103:23:44	REG #1 & #2 ADJ. #1-20° CCW, #2-30° CCW, 28.9V
104:21:12	ATM BAT #8 CAP TEST 12.1 AH
104:22:43	ATM BAT #5 CAP TEST 12.5 AH
105	REGULATOR WOULD NOT TURN OFF FROM C&D PANEL TWO OTHER REGULATORS HAVE BEEN REPORTED NOT TO TURN OFF. CBRM #6 ON DOY 150, CBRM #16 ON DOY 222
105:15:27	PCG BAT #6 CAP TEST 32.18
106:16:31	PCG BAT #8 CAP TEST 31.80
109:15:21	BAT 1 CHG/TRICKLE, CHG Δ = 2A FROM 2.3 TO .5 @ TRICKLE CHG
109:18:34	REG 2 POT BUMPED
109:18:41	REG 2 READJUSTED
110:01:11	REG #2 ADJ - ADJ 10° CW; OCV BEFORE & AFTER 28.9
110:20:53	MDA AFT LTS. 2&4 TROUBLE-SHOOTING PROCEDURE RUN. MDA LTS OPERATE
110: :37	REG #2 ADJ.AFTER: #2-29.1
110:14:33	EREP # 10
110:16:44	REG #2 READJ
112:12:51	REG #2 ADJ.AFTER: #2-29.1
112:14:07	EREP #11
112:16:08	REG #2 ADJ.RETURNED TO 28.9
112:17:46	EREP #12
113:13:43	REG #2 ADJ.
113:15:05	EREP #13
113:17:24	REG #2 ADJ.RETURNED TO 28.98
114:07:25	CREW REPORTED THUMP
114:14:16	EREP #14
114:17:55	EREP #15
114: :07	#8 FINE ADJ.GOAL 10° CW; CREW WENT "TOO FAR"
116:21:14	EREP #16A
117:02:20	#8 FINE ADJ.EQUAL TO BATT #5 DISCHARGE
117:20:32	EREP #17A
118	ATM BAT #10 CAP. TEST 11.7 AH
119:17:46	REG #1&2 ADJ.AFTER: #1-29.25 & #2-29.25
119:18:48	EREP #18B
119:20:19	REG #1&2 ADJ. BOTH RETURNED TO 29.0 VOLTS
120:15:00	LARGE SAS 5I @ TRICKLE CHG. 6.44 TO 5A
120:18:07	EREP #19
120:19:54	EREP #20
121:12:58	EREP #21
	EREP #22 CANCELLED
121:20:49	EREP #23

DAY:GMT	EVENTS/SL-3
122:12:16	EREP #24
122:16:33	EREP #25
122:20:02	EREP #26
123:02:30	CBRM #5 CHARGER MALFUNCTION
123:17:42	EREP #27
123:19:17	EREP #28
124:16:43	EREP #29
125:14:52	EREP #30 CANCELLED REG 1&2 OCV ADJ : 1-10° CW, 2-15° CW, #1-29.17, #2-29, 1
125:16:01	EREP #31
125:17:46	EREP #32
126:00:10	REG 2 ADJ. WAS 29.22, NOW 29. 18
126:15:20	EREP #33
126:16:40	EREP #34
127:14:29	EREP #35
128:00:07	EREP #36
128:15:39	EREP #37
129:01:46	TIMER PROBLEM
129:13:38	EREP #38
129:19:47	EREP #39
131:13:23	EREP #41
131:12:30	REG 1&2 ADJ. #1-15° CW & #2-10° CW, AFTER 1-29. 26 #2-29.34
131:15:40	REG 1 & 2 ADJ. #1-20° CCW & #2-25° CCW; AFTER #1-29.11 #2-29.14
132:11:17	HATCH OPEN - EVA
132:16:15	REG 2 ADJ. AFTER 10° CCW - 29.0
135:09:40 (SCHED)	CSM PWR XFER TO INTERNAL
135:11:10	REG XFER 1&2 OPEN; REG #1 & #2 ADJ #1-170° CCW, #2-165° CCW
135:13:29 (AOS)	SPG - AM, C&W PWR DWN
135:19:49 (SCHED)	CSM UNDOCKING
135:22:19	SPLASH DOWN

	EVENTS/SL-4
187:14:01:23	SL-4 LIFT OFF
187:17:18	TRACKING LTS ON
187:20:39	DOCKING LTS ON
187:22:02	SL-4 DOCKING
188:14:29	REG 1 & 2 ADJ, RESULTANT OCVS #1 - 28.8, #2 28.7
188:15:47	REG 1 & 2 ADJ. #1 = 29.2, #2 = 29.2
188:16:15	REG/XFER TIES CLOSED
188:16:57	SINGLE PT. GND TO CSM

DAY:GMT	EVENTS/SL-4
189:03:36	REG 2 OCV CHANGE. CREW ACCIDENTALLY BUMPED POT & ATTEMPTED TO RETURN IT TO ORIGINAL POSITION
189:18:46	REG 2 ADJ. #2 = 29.2
189:19:43	REG 1 ADJ. #1 = 29.30, #2 = 29.26
195:18:08	PCG #6 BATT CAP TEST 26.6 AH @ 32.5 VOLTS
196:22:01	KOHOUTEK MNVR, S019K
197:22:50	KOHOUTEK MNVR, S201K
198:14:41	KOHOUTEK MNVR, S232
201:16:11	EREP MNVR
202:17:10	EREP MNVR
203:16:26	EREP MNVR
203:17:59	EREP MNVR
204:15:47	EREP MNVR
204:17:20	EREP MNVR
205:15:33	EREP MNVR
206:03:13	BEGIN PWR XFER TO CSM
206:03:29	REG BUS 1 & 2 ADJ. #1 = 29.17, #2 = 29.11
206:04:05	REG BUS 1 ADJ. #1 = 29.13, #2 = 29.11
206:14:51	EREP MNVR
206:21:35	KOHOUTEK MNVR, S201K
207:02:23	KOHOUTEK MNVR, S063K
207:13:09	REG 1 & 2 ADJ. #1 = 28.97, #2 = 28.97
208:01:43	KOHOUTEK MNVR, S183K
208:13:15	REG BUS 1 & 2 ADJ. #1 = 29.14, #2 = 29.13
208:13:28	EREP MNVR
208:18:37	JOP 13 MNVR
208:23:19	KOHOUTEK MNVR, S019K
209:18:06	KOHOUTEK MNVR, S063K
210:00:01	EREP CAL MNVR
210:01:11	EREP MNVR
210:20:37	KOHOUTEK MNVR, S063
211:00:32	REG BUS 1 & 2 ADJ. #1 = 28.92, #2 = 28.93
211:16:49	KOHOUTEK MNVR, S063K
213:01:15	KOHOUTEK MNVR, S201K
213:05:35	KOHOUTEK MNVR, S201K
214:14:42	KOHOUTEK MNVR, S019K
215:00:02	KOHOUTEK MNVR, S183
215:15:34	KOHOUTEK MNVR, S019K
215:22:26	REG BUS 1 & 2 ADJ. #1 = 29.10, #2 = 29.18
215:22:37	EREP MNVR
215:23:21	REG BUS 2 ADJ. #1 = 29.09, #2 = 29.11
215:17:11	KOHOUTEK MNVR, S201K
217:21:51	KOHOUTEK MNVR, S019K
218:02:31	KOHOUTEK MNVR, S019K
218:16:32	KOHOUTEK MNVR, S063K
219:01:15	REG BUS #2 ADJ. #1 = 29.09, #2 = 29.20

DAY:GMT	EVENTS/SL-4
219:01:15	EREP MNVR
219:02:55	REG BUS #2 ADJ #1 = 29.09, #2 = 29.16
219:10:09	REG BUS #2 ADJ #1 = 29.09, #2 = 29.33
219:10:34	EREP MNVR
219:13:13	REG BUS #2 ADJ #1 = 29.09, #2 = 29.16
219:21:36	KOHOUTEK MNVR, S183K
220:15:37	REG BUS #1 & 2 ADJ #1 = 28.94, #2 = 28.92
220:15:51	JOP-18D MNVR
220:22:27	KOHOUTEK MNVR, S019K
222:01:23	KOHOUTEK MNVR, S063K
222:15:23	JOP-18D MNVR
222:23:10	KOHOUTEK MNVR, S063
223:16:17	KOHOUTEK MNVR, S063K
224:15:02	KOHOUTEK MNVR, S201K
224:18:41	JOP-18D MNVR
225:00:45	KOHOUTEK MNVR, S019K
225:17:58	JOP-18D MNVR
226:21:05	KOHOUTEK MNVR, S201
229:16:43	PCG #6 BATT CAP TEST 23.0 A.H. @ 32.6 VOLTS
230:18:54	REG BUS #1 & 2 ADJ #1 = 29.20, #2 = 29.08
230:19:39	KOHOUTEK MNVR, S201K
230:20:28	REG BUS #2 ADJ #1 = 29.20, #2 = 29.18
230:21:30	REG BUS #1 & 2 ADJ #1 = 28.91, #2 = 28.92
231:01:51	JOB-18D MNVR
231:14:16	JOP-18D MNVR
231:22:06	JOP-18D MNVR
232:15:07	JOP-18D MNVR
232:22:53	JOP-18D MNVR
233:11:38	REG 1 & 2 ADJ #1 = 29.4, #2 = 29.3
233:14:50	REG 1 & 2 ADJ #1 = 29.14, #2 = 29.13
233:11:50	EREP MNVR
233:22:06	JOP-18D MNVR
234:01:19	REG 1 & 2 ADJ #1 = 28.9, #2 = 29.2
234:14:26	KOHOUTEK MNVR, S063
234:21:05	REG 1 & 2 ADJ #1 = 29.15, #2 = 29.19
234:21:56	KOHOUTEK MNVR, S201K
235:10:27	EREP MNVR
235:15:17	KOHOUTEK MNVR, S183K
235:20:01	REG 1 ADJ #1 = 28.85, #2 = 29.19
235:20:36	JOP-18D MNVR
236:00:19	REG 1 & 2 ADJ #1 = 28.94, #2 = 28.92
236:18:47	REG 1 & 2 ADJ #1 = 29.25, #2 = 29.23
236:19:05	EREP MNVR
236:21:09	REG 1 & 2 ADJ #1 = 28.92, #2 = 28.89
236:23:52	KOHOUTEK MNVR, S019K
237: 4:03	REG 1 & 2 ADJ #1 = 29.03, #2 = 29.00

DAY:GMT	EVENTS/SL-4
237:14:37	JOP-18D MNVR
237:23:11	KOHOUTEK MNVR, S063K
238:13:10	KOHOUTEK MNVR, S201K
238:17:08	REG 1 & 2 ADJ #1 = 29.17, #2 = 29.20
238:17:42	EREP MNVR
238:20:59	REG 1 & 2 ADJ #1 = 29.0, #2 = 29.0
238:23:12	JOP-18D MNVR
239:12:44	EREP CAL MNVR
239:16:28	REG 1 & 2 ADJ #1 = 29.24, #2 = 29.16
239:17:00	EREP MNVR
239:18:59	REG 1 & 2 ADJ #1 = 29.0, #2 = 29.0
239:23:26	KOHOUTEK MNVR, S019K
240:11:48	KOHOUTEK MNVR, S019K
240:15:50	REG 1 & 2 ADJ #1 = 29.3, #2 = 29.3
240:16:13	EREP MNVR
240:18:28	REG 1 & 2 ADJ #1 = 29.0, #2 = 29.0
241:00:18	KOHOUTEK MNVR, S063
241:15:09	REG 1 & 2 ADJ #1 = 29.18, #2 = 29.19
241:15:30	EREP MNVR
241:20:28	KOHOUTEK MNVR, S063K
241:23:34	KOHOUTEK MNVR, S183K
242:16:44	KOHOUTEK MNVR, S-201K
243:00:06	REG 1 & 2 ADJ #1 = 29.48, #2 = 29.48
243:00:16	EREP MNVR
243:16:02	REG 1 & 2 ADJ #1 = 29.40, #2 = 29.30
243:17:13	EREP MNVR
243:22:18	KOHOUTEK MNVR S183K
244:01:25	KOHOUTEK MNVR S019K
244:15:15	REG 2 ADJ #1 = 29.40, #2 = 29.42
244:16:32	EREP MNVR
244:21:39	KOHOUTEK MNVR S063K
245:00:46	KOHOUTEK MNVR S201K
245:21:00	KOHOUTEK MNVR S063
246:14:02	REG 1 & 2 ADJ #1 = 29.61, #2 + 29.59
246:15:03	EREP MNVRS
246:18:05	REG L & 2 ADJ #1 = 29.40, #2 = 29.40
246:20:24	KOHOUTEK MNVR S019
247:01:04	KOHOUTEK MNVR
250:20:20	EREP MNVR
251:18:13	EREP MNVR
252:18:43	EREP MNVR
253:19:46	EREP MNVR
254:19:03	EREP MNVR
256:16:25	EREP MNVR
256:16:54	REG 1 & 2 ADJ #1 = 29.32, #2 = 29.25

DAY:GMT	EVENTS/SL-4
257:15:44	EREP MNVR
257:17:37	REG 1 & 2 ADJ #1 = 29.14, #2 = 29.16
257:23:54	KOHOUTEK MNVR S201K
258:13:03	KOHOUTEK MNVR S201
258:18:12	REG 1 & 2 ADJ #1 = 29.47, #2 = 29.50
258:18:12	EREP MNVR
258:21:21	REG 1 AND 2 ADJ #1 = 28.90, #2 = 28.95
259:11:08	REG 1 AND 2 ADJ #1 = 29.30, #2 = 29.30
259:11:17	EREP MNVR
259:17:30	EREP MNVR
259:20:57	REG 1 AND 2 ADJ #1 = 28.94, #2 = 28.94
260:00:13	KOHOUTEK MNVR S063K
260:16:46	REG 1 AND 2 ADJ #1 = 29.14, #2 = 29.16
260:17:41	EREP MNVR
260:19:51	REG 1 & 2 ADJ #1 = 28.93, #2 = 28.93
261:15:57	REG 1 & 2 ADJ #1 = 29.4, #2 = 29.4
261:16:07	EREP MNVR
261: 9:07	REG 1 & 2 ADJ #1 = 29.00, #2 = 29.03
261:22:20	REG 1 & 2 ADJ #1 = 29.53, #2 = 29.62
261:23:45	JOP-13 MNVR
262:01:28	REG 1 & 2 ADJ #1 = 29.06, #2 = 29.06
262:15:12	REG 1 & 2 ADJ #1 = 29.4, #2 = 29.4
262:15:26	EREP MNVR
262:18:49	REG 1 & 2 ADJ #1 = 28.93, #2 = 28.90
262:23:38	KOHOUTEK MNVR S019K
263:13:49	REG 1 & 2 ADJ #1 = 29.44, #2 = 29.44
263:14:42	EREP MNVR
263:18:04	REG 1 & 2 ADJ #1 = 28.91, #2 = 28.97
264:12:08	JOP-13 MNVR
264:12:14	REG 1 & 2 ADJ #1 = 29.42, #2 = 29.34
264:13:52	REG 1 & 2 ADJ #1 = 28.87, #2 = 28.91
264:15:22	REG 1 & 2 ADJ #1 = 29.27, #2 = 29.33
264:15:39	EREP MNVR
264:18:40	REG 1 & 2 ADJ #1 = 28.89, #2 = 28.89
264:23:49	KOHOUTEK MNVR S201
268:11:51	PCG #6 BATT CAP TEST 33.87 AH at 30.0 VOLTS
269:23:37	REG 1 & 2 ADJ #1 = 29.09, #2 = 28.94
270:12:20	REG 1 & 2 ADJ #1 = 28.90, #2 = 28.78
271:03:49	CSM TO INTERNAL POWER
271:04:44	REG 1 & 2 ADJ #1 = 29.07, #2 = 29.80
271:04:54	REG/XFER TIES TO "OPEN"
271:05:59	SINGLE PT GND TO AM
271:15:16	SL-4 SPLASHDOWN
271:15:16	BATT #2 CAP TEST 31.2 AH AT 30.0 VOLTS
271:18:28	BATT #4 CAP TEST 38.22 AH AT 30.0 VOLTS

DAY;GMT	EVENTS/SL-4
271:20:30	BATT #6 CAP TEST 33.37 AH AT 30.0 VOLTS
271:22:17	BATT #8 CAP TEST 30.94 AH AT 30.0 VOLTS
271:00:19	BATT #1 CAP TEST 38.74 AH AT 30.0 VOLTS
272:04:11	BATT #3 CAP TEST 31.94 AH AT 30.0 VOLTS
272:07:28	BATT #6 CAP TEST (SECOND) 37.72 AH AT 30.0 VOLTS
272:09:52	BATT #8 CAP TEST (SECOND) 32.01 AH AT 30.0 VOLTS
272:12:29	BATT #5 CAP TEST 31.60 AH AT 30.0 VOLTS
272:14:35	BATT #7 CAP TEST 31.41 AH AT 30.0 VOLTS
272:16:33	REG/XFER TIES TO "CLOSED" - AM & ATM RE-PARALLED
272:18:19	POWER DOWN-AM BATT #2 "OFF" - LAST COMMAND SENT TO SKYLAB (See Table 6.II for complete Power-Down Sequence).

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C&W SYSTEM EVENTS - SL-1/2

TIME	ALARM*	EVENT
13:17:25		C&W SYSTEM ACTIVATION
17:28	C1 & C2	PRIMARY COOLANT TEMPERATURE LOW-DUE TO A LACK OF HEAT LOAD BROUGHT ON BY THE LIMITED AVAILABLE POWER CONDITION.
18:27	C1 & C2	ACS CMG SATURATE -
18:28	W1 & W2	ACS HI RATE -
21:54	W1 & W2	AT AOS GOLDSTONE THE CREW REPORTED THAT THREE FIRE ALARMS HAD OCCURRED. THESE ALARMS ORIGINATED FROM FIRE SENSOR CONTROL PANEL 639 FIRE SENSOR #2, IN THE OWS SLEEP COMPARTMENT. IT IS FELT THAT THE ALARMS WERE CAUSED DUE TO EXCESSIVELY HIGH TEMPERATURES IN THE VICINITY. SENSOR POWERED DOWN.
14:03:05	C1 & C2	BATTERY #8 STATE OF CHARGE ALARM - #8 AMP HOUR INTEGRATOR C/B (PRI. & SEC.) WAS INADVERTENTLY OPENED BY THE CREW. THIS RESET THE INTEGRATORS TO ZERO.
03:10	C1 & C2	ACS 2/3 RATE GYRO AND ACS CMG SATURATE - CAUSED BY DRIFTING GYROS
03:15	C1 & C2	ACS CMG SATURATE - DRIFTING GYROS
16:05	C1 & C2	ACS CMG SATURATE - SLEEP COMPARTMENT SENSOR ACTIVATED. ALL SENSORS TESTED OK.
21:11	C1 & C2	SIEVE A GAS FLOW - MOLE SIEVE A ACTIVATION AFTER BAKEOUT. NORMAL OPERATION AFTER BED BAKEOUT.
21:40	W1 & W2	OWS HEAT EXCHANGER FIRE ALARM -
	F1 & F2	ALARM WAS DETERMINED TO BE CAUSED BY THE HIGH RADIATION LEVEL IN THE SOUTH ATLANTIC ANOMALY. THE ALARM ORIGINATED FROM FIRE SENSOR CONTROL PANEL 392 AND SENSOR #2.
23:14	C1 & C2	ALARMS UNEXPLAINED BY CREW OR GROUND
23:16	C1 & C2	THERE ARE NO TM MEASUREMENTS THAT MONITOR THESE FUNCTIONS. (1) MOLE SIEVE CYCLE TIMER, (2) MOLE SIEVE BED TEMPERATURE HIGH, AND (3) C&W SIGNAL CONDITIONER POWER. CREW POSSIBLY TESTING TO SEE WHICH SWITCHES CAN BE ENABLED.

* C - CAUTION
W = WARNING
F = FIRE
R = RAPID LOSS OF PRESSURE

C&W SYSTEM EVENTS - SL-1/2 (Continued)

TIME	ALARM	EVENT
16:01:44	W1 & W2	SECONDARY AM COOLANT LOOP ACTIVATED FROM THE GROUND.
17:17:38	W1 & W2	CSM ALARM - CSM WATER DUMP ACTIVATED CLUSTER
18:00:19	W1 & W2	PRIMARY AM COOLANT LOOP ACTIVATED FROM THE GROUND.
23:33	W1 & W2	CREW ALERT #1 - STDN CREW ALERT CAPABILITY TEST.
23:34	W1 & W2	CREW ALERT #2 - STDN CREW ALERT CAPABILITY TEST.
19:00:40	W1 & W2	PRIMARY AM COOLANT LOOP ACTIVATED FROM THE GROUND.
01:11	C1 & C2	AT AOS CREW REPORTED A RATE GYRO ALARM. THE CAUSE WAS GYRO DRIFT.
08:22		CREW TRANSCRIPTS (CHANNEL B) - NINE SWITCHES INHIBITED; 8 BATT CHARGE LOW & 1 $PPCO_2$ B HIGH
19:40	W1 & W2 F1 & F2	FIRE ALARM - OWS HEAT EXCHANGER FIRE SENSOR #1 (392-1) WAS TRIGGERED AGAIN BY RADIATION IN THE SOUTH ATLANTIC ANOMALY.
20:47		FIRE SENSOR 392-1 (ABOVE) GAIN WAS REDUCED FROM "4" TO "3".
20:08:40	C1 & C2	AT AOS THE CREW REPORTED ON OWS BUS LOW ALARM. REAL TIME TROUBLE SHOOTING FOUND ONE OWS POWER FEEDER C/B AND BOTH C&W OWS LOW VOLTAGE SENSE C/B's OPEN. CREW INHIBITED C&W INDICATION AND GROUND INFORMED THEM TO MAINTAIN THAT CONFIGURATION UNTIL FURTHER NOTICE.
11:16		C&W AND EMERGENCY #1 SUBUNITS POWERED DOWN FOR POWER CONSERVATION - CREW AWAKE PERIODS.
18:54	C2	ACS CMG SATURATE.
21:00:50	C2 & W2	ACS RATE GYRO, ACS CMG SATURATES ACS HI RATE, AND ACS THRUSTER STUCK CAUSED BY A FAILURE IN A Z AXIS GYRO.
02:25	W2	PRIMARY AM COOLANT LOOP ACTIVATED FROM GROUND.
02:59		C&W AND EMERGENCY #1 SUBUNITS POWERED UP - CREW SLEEP PERIOD.
11:15		C&W AND EMERGENCY #1 SUBUNITS POWERED DOWN FOR POWER CONSERVATION - CREW AWAKE PERIOD.
19:45	W2	TWO CSM ALARMS - CRYO PRESSURE WAS OUT OF TOLERANCE.

TIME	ALARM	EVENT
22:03:21		C&W AND EMERGENCY #1 SUBUNITS POWERED UP - CREW SLEEP PERIOD.
11:36		C&W AND EMERGENCY #1 SUBUNITS POWERED DOWN FOR POWER CONSERVATION - CREW AWAKE PERIOD.
16:24	C2	MOLE SIEVE GAS FLOW B LOW - MOLE SIEVE B FAN WAS DEACTIVATED.
19:18		OWS BUS LOW C&W ALARM TROUBLE-SHOOTING COMPLETED. ALL C/Bs WERE CLOSED. C&W OWS LOW VOLTAGE ENABLED - NO TRIP. SYSTEM WORKING OK.
23:26	W2	PRIMARY AM COOLANT LOOP ACTIVATED FROM GROUND.
23:03:09		C&W AND EMERGENCY #1 SUBUNITS POWERED UP - CREW SLEEP PERIOD.
11:20		C&W AND EMERGENCY #1 SUBUNITS POWERED DOWN FOR POWER CONSERVATION - CREW AWAKE PERIOD.
24:03:26		C&W AND EMERGENCY #1 SUBUNITS POWERED UP - CREW SLEEP PERIOD.
12:49		C&W AND EMERGENCY #1 SUBUNITS POWERED DOWN FOR POWER CONSERVATION - CREW AWAKE PERIOD.
14:26		CREW VERIFIED THAT ALL FIRE SENSORS HAVE BEEN CONFIGURED TO BUS #2 POSITION.
20:29	C2	ACS 2/3 RATE GYRO - 3 - 1 GYRO WENT INTO HEAVY OSCILLATIONS.
25:02:40		C&W AND EMERGENCY #1 SUBUNITS POWERED UP - CREW SLEEP PERIOD.
11:08		C&W AND EMERGENCY #1 SUBUNITS POWERED DOWN FOR POWER CONSERVATION - CREW AWAKE PERIOD.
12:59	W2	PRIMARY AM COOLANT LOOP ACTIVATED FROM GROUND
13:57	C2	CONDENSATE TANK ΔP - DUE TO A LEAKY QUICK-DISCONNECT CONNECTOR (QD).
13:39	C2	PRIMARY COOLANT LOOP TEMPERATURE LOW - OCCURRED JUST AFTER SWITCH TO BYPASS POSITION WAS MADE, CREWMAN REPORTED A BIG BANG.
13:41	W2	EVA #1 COOLANT LOOP TEMPERATURE LOW - COOLANT LOOPS FROZE DUE TO A LACK OF HEAT LOADS.
13:49	W2	EVA #1 PUMP ΔP - CREW IS PREPARING FOR EVA.
15:05	W2 & R2	RAPID ΔP #2 - CAUSED BY OPENING OF AM/OWS HATCH WITH A ΔP PRESENT ACROSS COMPARTMENTS. OCCURRED PRIOR TO EVA AFT LOCK DEPRESS.

C&W SYSTEM EVENTS - SL-1/2 (Continued)

TIME	ALARM	EVENT
25:16:04	W2	PRIMARY COOLANT LOOP INVERTER #1 POWERED UP.
16:33	W2 & F2	FIRE ALARM ORIGINATED AT FSCP #392 SENSOR #2. FALSE ALARM WAS CAUSED BY SUNLIGHT ENTERING AFT COMPARTMENT WHEN EVA HATCH WAS OPENED.
18:06	C2	CONDENSATE TANK ΔP ALARM - AGAIN CAUSED BY A LEAKY QD.
19:37	C2	SECONDARY COOLANT LOOP TEMPERATURE LOW ALARM - DUE TO A LACK OF HEAT LOADS ON THE LINE.
19:39	C2	MOLE SIEVE A GAS FLOW LOW ALARM - MOLE SIEVE A FAN WAS POWERED UP. POST EVA ACTIVATION.
19:40	C2	MOLE SIEVE A & B GAS FLOW LOW ALARM - MOLE SIEVES FANS POWERED DOWN DUE TO LOUD NOISES IN THE SYSTEMS. PROBLEM IS TIED IN WITH LOW COOLANT LOOP TEMPERATURES.
26:01:08	W2	SECONDARY AM COOLANT LOOP ACTIVATED FROM GROUND. THE PLAN IS TO EXPOSE STUCK TCV VALVE TO THERMAL SHOCKS.
02:40	W2	SECONDARY COOLANT LOOP ACTIVATED FROM GROUND. C&W AND EMERGENCY #1 SUBUNITS POWERED UP - CREW SLEEP PERIOD.
04:40	W1 & W2	EVA 1 & 2 PUMP ΔP-SUS LOOP POWERED UP TO HELP WITH LOW COOLANT TEMPERATURE PROBLEM.
27:02:15	W1 & W2	PRIMARY COOLANT LOOP POWERED UP.
02:17	C1 & C2	PRIMARY COOLANT LOOP TEMPERATURE LOW. TEMPERATURE OF LOOP APPROX. 30°F.
02:21		TROUBLESHOOTING FOR THE LACK OF EVA PUMP ΔP ALARM AT PUMP ACTIVATION. RESULTS SHOWED NO ALARMS AT ACTIVATION.
16:44		ACS 2/3 RATE GYRO ALARM - CAUSED BY COMPUTER SWITCHOVER AND GROUND NOT UPDATING DRIFT COMPENSATION IN TIME.
18:15	W1 & W2	PRIMARY COOLANT LOOP ACTIVATED FROM GROUND.
18:42	W1 & W2 F1 & F2	FIRE SYSTEM TEST PERFORMED PER. SYSTEMS CHECKLIST. SIDE #2 OF FIRE SENSOR CONTROL PANEL 392 DID NOT TEST CORRECTLY.
28:13:07		CREW REPLACED FSA (392-2) AND FSCP (392). FSCP SIDE #2 WAS MARKED "BAD" AND THE USED FSA AND FSCP WERE STOWED IN LOCKER 432 AS SPARES. FSCP MAY BE USED IN THE OWS IN POSITIONS 530 AND 619.

C&W SYSTEM EVENTS - SL-1/2 (Concluded)

TIME	ALARM	EVENT
28:13:54	W1 & W2	PRIMARY COOLANT LOOP ACTIVATED FROM GROUND.
29:15:38	C1 & C2	ACS CMG SATURATE - CAUSED BY EREP PASS
16:49	W1 & W2	ADDITIONAL SECONDARY COOLANT LOOP PUMP POWERED UP IN AN ATTEMPT TO FREE STUCK TCV VALVE.
22:07	W1 & W2	TWO PUMPS IN SECONDARY AM COOLANT LOOP ARE COMMANDED ON IN ATTEMPT TO FREE STUCK TCV VALVE.
22:09	C1 & C2	SECONDARY COOLANT LOOP TEMPERATURE LOW CAUSED STUCK TCV VALVE.
30:14:35	W1 & W2	TWO PUMPS IN SECONDARY AM COOLANT LOOP WERE COMMANDED ON AN ATTEMPT TO FREE STUCK VALVE. VALVE WAS FREED.
31:23:14	C1 & C2	$PPCO_2$ B HI - CREW IS TOLD TO INHIBIT PARAMETER SINCE BED IS NOT ACTIVE.
33:22:53	W1 & W2 F1 & F2	FIRE ALARM - VERIFIED BY MOPS - NO CREW VERIFICATION.
34:10:57	C1 & C2	MOLE SIEVE A GAS FLOW - MOLE SIEVE A FANS CYCLED OFF AND ON.
10:58	C1	MOLE SIEVE B GAS FLOW - MOLE SIEVE B FANS CYCLED OFF AND ON.
16:23		$PPCO_2$ HI ALARM REPORTED BY CREW - CAUSED BY BED CYCLING AND THE CORRESPONDING RISE IN CO_2.
35:11:11	C1, W2, R2	RAPID ΔP SYSTEM CHECK - ALL OK.
	C2, W1, R1 C1, W2, F2	FIRE SYSTEM CHECK FROM 206 PANEL
	C2, W1, F1	FIRE SYSTEM CHECK FROM 206 PANEL - ALL OK.
37:08:50	C1 & C2	MOLE SIEVE B FAN CYCLED OFF AND ON TO CHECK FOR CAUTION #2 ALARM.
08:53	W1 & W2	ADDITIONAL PUMP IN SECONDARY AM COOLANT IS ACTIVATED.
08:56		SUS LOOP #1 CYCLED ON & OFF 3 TIMES, NO C&W EVA PUMP ΔP ALARM OCCURRED. NOTE: CREW EXPLAINED DURING DEBRIEFING THAT A RAPID ΔP ALARM OCCURRED DURING REPRESS AFTER EACH EVA.
40:05:10	C1	$PPCO_2$ A HI - MOLE SIEVE FANS WERE SHUT DOWN PREVIOUSLY. NORMAL OPERATION IN A NO FLOW CONDITION FOR THE CO_2 TO BUILD UP.
05:33		C&W SYSTEM DEACTIVATED FOR STORAGE MODE.

C&W SYSTEM EVENTS SL-3

TIME	ALARM	REMARKS
76:22:29		C&W System is powered up.
23:53	C1&C2,W1&W2 F1&F2,R1&R2	Caution and Warning System tests per activation procedure. NO PROBLEMS.
77:16:36	W1&W2 (3 times)	CSM MALFUNCTION - 3rd CSM Alarm that has occurred today. CSM people feel it is EMI.
19:10	W1&W2	CSM MALFUNCTION - A short in the Circadian Data System caused the alarm. Some 70 amp spikes lowered the bus voltage to 25 volts. The System shorted open relieving the problem.
23:26	C1&C2 (2 times)	SIEVE A GAS FLOW - Mole Sieve fans were powered up. Sporadic air flow caused the alarm. Crew inhibited the parameters (SIEVE A&B Gas flow.)
81:10:42	W1&W2	CSM MALFUNCTION - Quad B Temp Low, Secondary Quad 3 heaters are selected.
23:36		Crew reported the following Switches inhibited on panel 207. Rate Gyro Condensate Tank ΔP, Sieve A&B $PPCO_2$ Sieve A&B Gas Flow
82:19:40	W1&W2	PRI COOLANT FLOW - Primary coolant loop powered up via ground Command.
83:03:20	W1&W2 C1&C2	CSM MALFUNCTION - No problems in CSM found. This alarm occurred at approximately the same time as the ATM bus short although no connection between the short and the alarms were found.
13:27	W1&W2	CREW ALERT - STDN Check of Crew Alert 1 and Crew Alert 2 capability.

C&W SYSTEM EVENTS SL-3 (Continued)

TIME	ALARM	REMARKS
83:17:43:29 17:44:06	W1&W2,F1&F2 W1&W2,F1&F2	FIRE ALARM - Wardroom Fire Sensor 633-2 was triggered by high UV through the Wardroom window. The vehicle was just coming out of Z-LV in which the Wardroom window is facing the Earth. The Sunshade had been taken off the window for picture taking.
85:14:26	W1&W2	PRI COOLANT FLOW - Second pump in primary AM Coolant loop powered via ground command.
86:00:05	W1&W2,R1&R2	RAPID P - An expected Rapid ΔP alarm occurred during Airlock repress after EVA.
87:00:33	W1&W2	PPO_2 LOW - Crew reconfigured to: PPO_2 #1 - Control PPO_2 #2 - MONITOR PPO_2 #3 - OFF PPO_2 #3 Triggered the alarm.
13:45 13:49	C1&C2 C1&C2	SIEVA A GAS FLOW - No explanation over loop.
13:54	W1&R1	RAPID ΔP - Rapid ΔP drill performed by crew.
19:11	W1&W2,F1&F2	FIRE - Fire test performed per HK Task 10-B.
23:51	C1&C2	SIEVE A GAS FLOW - This alarm was caused by troubleshooting on Sieve B secondary fan circuit.
90:12:08	C1	SIEVE A $PPCO_2$ HI - Crew was advised about bed cycling. They were told not to inhibit parameter unless alarms became more frequent.
91:02:48	C1&C2	CMG SATURATE - Alarm caused by high vehicle momentum.
17:10 17:10 17:19	C1 W1 C1	CMG SATURATE, HI - RATE, AUTO TACS, & THRUSTER STUCK - High vehicle momentum caused alarms.

TIME	ALARM	REMARKS
91:19:XX	C1	CMG SATURATE (?) - High momentum related to previous alarm is still present.
92:11:42	W1&W2	CSM MALFUNCTION - Quad B Temp Low transducer is reading intermittent.
15:20	W1&W2	CSM MALFUNCTION - Quad B Temp Low transducer is still reading intermittent Crew inhibited parameter in CSM by 16:00 HRS.
16:00	W1&W2	CSM MALFUNCTION - Quad D temp low.
20:26 TO 20:28	C1&C2 (4 times)	CMG SATURATE - Venting of vehicle per Experiment put torque on vehicle causing CMG's to saturate.
93:02:55		Crew verified the following switches inhibited on panel 207: Condensate Tank ΔP LOW Sieve A&B $PPCO_2$ HIGH
97:17:16 17:18	W1&W2 W1&W2	CSM MALFUNCTION - Alarm caused by troubleshooting on the CSM accumulators.
99:13:37 TO 13:42	C1 (7 times)	SIEVE A GAS FLOW - These expected alarms were caused by Mole Sieve Bakeout. Crew was told to inhibit parameter.
100:13:30 TO 13:34	W1&W2 (6 times)	SEC COOLANT FLOW - C/B kept tripping while trying to activate Secondary AM Coolant loop. Loop was finally powered using a different configuration.
14:21	W1&W2 (2 times)	SEC COOLANT FLOW - Minor troubleshooting on above problem.
18:39	W1&W2 (5 times)	EVA 2 PUMP ΔP - SUS Loop #2 is activated.
103:12:53	W1&W2	SEC COOLANT FLOW - Second pump activated in Secondary Coolant loop to support EVA.

C&W SYSTEM EVENTS SL-3 (Continued)

TIME	ALARM	REMARKS
103:13:31	W1 (2 times)	EVA 2 PUMP ΔP - SUS loop is activated for EVA.
16:13		C&W Side #2 and EMERG Side #2 is powered down for off loading during EVA.
17:48	W1	This alarm was on for over 12 minutes. Crewman was unable to recall the alarm. Later troubleshooting found no problems with system.
19:13	C1 (2 times)	CMG SATURATE - High vehicle momentum.
19:54	C1 (3 times)	CMG SATURATE - High vehicle momentum.
20:18	C1 (2 times)	CMG SATURATE - High vehicle momentum.
21:08 21:11	W1 W1	EVA 2 PUMP ΔP (?) - Alarms are caused by EVA panel power down.
22:03		C&W Side 2 and EMERG Side 2 are powered up.
104:13:45		Crew verified the following switches inhibited on panel 207: Sieve A&B Gas FLOW Sieve A&B $PPCO_2$ OWS GAS Interchange Condensate Tank ΔP
13:57		Crew performed lamp test on panel 207. No burned out lights were found. This test was performed because of alarm unable to be recalled on DAY 103.
10[illegible]:18:24	W1&W2 F1&F2 R1&R2	Crew reported that Fire and Rapid ΔP tests per HK tasks 10-B were performed satisfactorily.

C&W SYSTEM EVENTS SL-3 (Continued)

TIME	ALARM	REMARKS
109:03:44	C1&C2	OWS GAS INTERCHANGE - This alarm was caused by sporadic air flow. The crew inhibited the parameter.
111:21:45	C1&C2 W1&W2	HK task 70 H, Warning System tests, was performed. This procedure was initiated to check the memory recall capability of the C&W system. The system performed satisfactorily.
114:01:05	W1&W2 F1&F2	FIRE - This alarm was caused by Experiment S073/T025 which uses an unfiltered window. The cover was removed from a SAL window for UV photography.
116:01:35 01:50	C1&C2 C1&C2	SIEVE A GAS FLOW - This alarm was caused by sporadic gas flow during Sieve Bed cycling.
23:16	C1&C2	EMERG PWR - Crewman stated that he accidentally opened a C&W C/B.
117:00:49	C1&C2 W1&W2 F1&F2 R1&R2	Crew reported the satisfactory completion of HK test 10-B1 and 10-B2 which are Fire sensor and Rapid ΔP system verifications.
00:56	C1&C2 W1&W2 R1&R2	EMERG SNSR PWR (?) - Crewman accidentally opened another C&W C/B. Rapid ΔP alarm occurred upon reset.
118:14:49 14:51	C1 C1	OWS GAS INTERCHANGE - Crew enabled the parameter because the AM duct fan was to be replaced. After the alarms they immediately inhibited the parameter. Replacing fan resulted in no appreciable increase in gas flow.
120:02:54	C1	SIEVE A GAS FLOW - Sporadic gas flow caused the alarm.
02:55	C1	SIEVE B GAS FLOW - Sporadic gas flow caused the alarm.

C&W SYSTEM EVENTS SL-3 (Concluded)

120:14:38:11	C1	CMG SATURATE - High vehicle momentum caused the alarm.
14:38:32 14:38:34	C1 W1&R1	EMERG PWR, RAPID ΔP - The crew said it was possible they accidentally flipped the reset switch. Data shows the Caution alarm occurring probably when the crewman switched Emergency power #1 switch to OFF. The Rapid ΔP alarm occurred when the switch was repositioned to ON.
14:39:01 14:39:29 15:09:54 15:14:48 15:16:22 15:18:10 18:18:55	C1&C2 C1&C2 C1 C1 C1 C1 C1	ACS MALFUNCTION (CMG SATURATE) - High vehicle momentum believed to be caused by experiment venting. TACS was used.
123:07:35	C1&C2	SIEVE A GAS FLOW - Sporadic air flow at Mole Sieve Bed cycling caused the alarm. Crew inhibited both Sieve A&B Gas Flow.
20:35 21:22	C1&C2 C1&C2	ACS MALFUNCTION (CMG SATURATE) - High vehicle momentum caused the alarm. TACS was fired at 2nd alarm.
125:14:08	W1&W2 F1&F2 R1&R2	Crew reported Fire and Rapid ΔP tests were performed satisfactorily.
16:46	C1&C2	CMG SATURATE - High vehicle momentum from EREP pass caused the alarm.
130:11:20	W1&W2	CSM MALFUNCTION - The crew performed T minus 5 day entry procedure which included CSM C&W checks. No problems.
132:14:01	W1&R1	RAPID ΔP - This was an expected alarm which occurred after the EVA during Airlock repressurization.
135:13:17		SL/3 Deactivation is in progress. C&W system is powered down.

C&W SYSTEM EVENTS SL-4

TIME	ALARM	REMARKS
188:17:18		C&W System is powered up per Activation C/L.
19:37		C&W checks are performed. These include: Fire Sensor Test Fire System Test Rapid ΔP System Test Warning Test Caution Test No problems occurred.
189:21:34	W1, W2	CSM MALF - Crew was working in CSM at the time of the alarm. Data verified the CSM trigger.
190:21:16	W1, W2	CREW ALERT - HK Task 60G, Crew Alert Warning test is performed.
21:21	W1, W2	CREW ALERT - HK Task 60G, Crew Alert Warning test is performed.
23:20	W1, W2	CSM MALF - CSM Operations in progress.
191:00:33	W1, W2	PRI COOL FLOW - Primary Coolant loop reservicing operations are in progress.
00:36	W1, W2	PRI COOL FLOW - Primary Coolant loop reservicing operations are in progress.
00:55	W1, W2	PRI COOL FLOW - Pump ? commanded on via ground uplink.
03:44	W1, W2	CREW ALERT 1 - Retest of HK Task 60G.
03:45	W1, W2	CREW ALERT 2 - Retest of HK Task 60G.
193:01:47	C1, C2	ACS MALF (RATE GYRO) - Alarm was verified by MOPS.
15:51	W1, W2	PRI COOL FLOW - Pump C commanded on via ground uplink.
16:42	C1, C2 (3 times)	CONDENSATE TANK ΔP - Alarms were verified by MOPS.

C&W SYSTEM EVENTS SL-4 (Continued)

TIME	ALARM	REMARKS
194:00:19	W1, R1, W2, R2	RAPID ΔP - This was an expected alarm which occurred during the Airlock re-pressurization after the EVA.
197:14:32	W1, W2	PPO_2 LOW - This was an expected alarm caused by PPO_2 sensor testing per HK 60V.
198:15:40	C1, C2	ACS MALF (AUTO TACS) - Caused by S232 operations.
201:20:10	W1, W2	CSM MALF - This alarm was caused by switching a pump on the CSM Glycol loop per CSM housekeeping task CM-7.
207:14:56 14:58	C1, C2 C1, C2	SIEVE B GAS FLOW - Fan power switch to "OFF" caused the gas flow to stop while performing HK task 11A.
210:23:20 to 23:50	C1, C2 R1, R2 F1, F2 W1, W2	House Keeping Task 28E is performed. This includes Emergency System Checks, Rapid ΔP System Checks, and Fire Sensor Checks.
214:15:12 15:14	W1, W2 W1, W2	CSM MALF - There was an incorrect configuration in the CSM at the time a command was uplinked.
215:22:33	C1, C2	SIEVE B GAS FLOW - Mole Sieve fan off loaded for EREP 15.
216:03:58	C2, W2	Crew inadvertently opened C&W Converter #1 and EMERG Converter #2 CBs.
219:15:59	C1, C2	ACS MALF (RATE GYRO) - Y3 rack gyro output was noisy.
220:12:53	W1, W2	PRI COOL FLOW - Coolant loop pump activated by the crew.
225:03:25	C1, C2	ACS MALF (CMG SAT) - TACS were used to desaturate vehicle.

TIME	ALARM	REMARKS
226:15:08	W1, W2	PRI COOL FLOW - A second pump was commanded on to support the EVA.
19:06	W1 (3 times)	CLUSTER ATT. (Hi-Rate) - Large torques on vehicle produced by EVA crewmen caused the alarms.
19:07	C1 (4 times)	ACS MALF (CMG SAT) - Large torques on vehicle produced by EVA crewmen caused the alarms.
23:11	W1	CLUSTER ATT. (Hi-Rate) - Large torques on vehicle produced by EVA crewmen caused the alarms.
23:16	C1	ACS MALF (CMG SAT) - Large torques on vehicle produced by EVA crewmen caused the alarms.
23:51	W1, R1 (2 times)	RAPID ΔP - This expected alarm was caused by repressurization of the Airlock per EVA procedure.
230:14:51	W1, W2	PRI COOL FLOW - A second pump was commanded on to support the EVA.
20:13	C1	ACS MALF (CMG SAT) - Caused by large torques produced by crewmen during EVA.
20:13	W1	CLUSTER ATT. (THRUSTER STUCK) - Caused by large torque produced by crewmen during EVA.
20:14	C1	ACS MALF (CMG SAT) - Caused by large torques produced by crewmen on EVA.
20:53	C2	ACS MALF (CMG SAT) - Caused by large torques produced by crewmen on EVA.
21:01	W1, R1 (2 times)	RAPID ΔP - This expected alarm was caused by repressurization of the Airlock per EVA procedure.

C&W SYSTEM EVENTS SL-4 (Continued)

TIME	ALARM	REMARKS
232:00:33	C1, C2	ACS MALF (CMG SAT) - Caused by data maneuver.
01:40	C1, C2	ACS MALF (CMG SAT) - Caused by data maneuver.
14:06	W1, F1 W2, F2	FIRE - This false alarm was caused by high radiation through the SAA.
233:11:47	C1, C2	ACS MALF (CMG SAT) - Caused by EREP data maneuver.
12:39	C1, C2	SIEVE B GAS FLOW - Fan was off-loaded for EREP pass.
236:20:58	C1, C2	ACS MALF (CMG SAT) - Caused by data maneuver.
239:17:43	C1, C2	ACS MALF (CMG SAT) - Caused by data maneuver.
18:05	C1, C2	ACS MALF (CMG SAT) - Caused by data maneuver.
240:00:00	C1, C2 W1, W2 F1, F2 R1, R2	Housekeeping task 28E was performed satisfactorily by the crew. This included Emergency System Verification, Rapid ΔP System Verification, and Fire Sensor Verification.
243:00:14	C1, C2	C&W POWER 1 - Crew cycled C&W Converter 1 C/B.
02:22	C2	C&W System powered down for EREP.
02:25	W1, W2 C1, C2	C&W System powered up.
247:10:47	W1, W2	CSM MALF - Quad B Temp in CSM.
248:16:38	W1, W2	PRI COOL FLOW - The loop was activated to reduce the workshop temps during HI Beta Angles.

C&W SYSTEM EVENTS SL-4 (Continued)

TIME	ALARM	REMARKS
252:21:16	W1, F1 W2, F2	FIRE - This false alarm was caused by high radiation through the SAA.
253:04:30		An unscheduled C&W/SIA Interface Test was performed. No Interface Malfunction detected.
259:19:00	C1, C2	ACS MALF (AUTO TACS) - The vehicle drifted out of attitude during an EREP pass.
261:22:14		Crew Inhibited all 8 BATT CHARGE LOW Parameters. This was performed to prevent alarms during upcoming data-take maneuvers. Also, high OCV's have caused large divergences between the actual and AMP HR integrator S[illegible]s
264:11:17	C1, W1	Alarms caused by powering down C&W #2 and EMERG #1 for data take maneuvers.
264:11:17		C&W Side 2 and EMERG Side 2 are off loaded for JOP 13 and EREP pass.
19:13		C&W Side 2 and EMERG Side 2 powered up.
265:14:05 to 14:19	W1, W2 (8 times)	CSM MALF - Crew having problems putting CSM Batt 4 on line.
266:12:28	W1, W2	PRI COOL FLOW - A second pump was commanded on to support the EVA.
20:41	R1, W1 R2, W2	RAPID ΔP - This expected alarm occurred during Airlock repressurization after the EVA.
23:49	C1, C2	CNDST TANK ΔP - The crew enabled Condensate Tank Switch (PNL 207) to verify that the tank pressure was zero.

C&W SYSTEM EVENTS SL-4 (Concluded)

TIME	ALARM	REMARKS
268:02:12		Crew inhibited the following parameters to preclude alarms which might be caused by ground testing: ATM Canister Pump ΔP ATM Canister Coolant Temp ATM Canister Heater Temp
271:05:59		C&W System is powered down per SL-4 deactivation procedure.

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Table 6.II Skylab EPS Power Down Sequence

Command	SITE/time*	Event
AM045	CRO/39:04:41	PCG5 to Reg 1
AM046		PCG6 to Reg 1
AM047		PCG7 to Reg 1
AM048		PCG8 to Reg 1
AM193	GDS/39:15:11	ATM1/XFR1 Open
AM194		ATM2/XFR2 Open
AM152		Batt 2 DISCH-LIMIT-INHIBIT
AM052		PCG2 to Reg 2
AM012		SAS2 to PCG3
AM042	VAN/39:17:13	PCG2 to Reg 1
AM002		SAS2 to PCG2
AM142		Batt 2 DISCH-LIMIT-AUTO
AM154	HAW/39:18:20	Batt 4 DISCH-LIMIT-INHIBIT
AM054		PCG4 to Reg 2
AM014		SAS4 to PCG1
AM044	HAW/39:20:04	PCG4 to Reg 1
AM004		SAS4 to PCG4
AM144		Batt 4 DISCH-LIMIT-AUTO
AM156		Batt 6 DISCH-LIMIT-INHIBIT
AM056		PCG6 to Reg 2
AM016		SAS6 to PCG7
AM116	VAN/39:22:07	Batt 6 - Off
AM046		PCG6 to Reg 1
AM006		SAS6 to PCG6
AM146		Batt 6 DISCH-LIMIT-AUTO
AM158		Batt 8 DISCH-LIMIT-INHIBIT
AM058		PCG8 to Reg 2
AM018		SAS8 to PCG5
AM106	GWM/39:23:04	Batt 6 - On
AM111	VAN/39:23:45	Batt 1 - Off
AM118	CYI/40:00:04	Batt 8 - Off
AM048		PCG8 to Reg 1
AM008		SAS 8 to PCG8
AM148		Batt 8 DISCH-LIMIT-AUTO
AM101	MAD/40:00:18	Batt 1 - On
AM151		Batt 1 DISCH-LIMIT-INHIBIT
AM051		PCG1 to Reg 2
AM011		SAS1 to PCG2
AM108	HSK/40:00:53	Batt 8 - On
AM041	HSK/40:02:32	PCG1 to Reg 1
AM001		SAS1 to PCG1
AM141		Batt 1 DISCH-LIMIT-AUTO
AM153	HSK/40:04:13	Batt 3 DISCH-LIMIT-INHIBIT
AM053		PCG3 to Reg 2
AM013		SAS3 to PCG4

*Time given in Day of Year, GMT hours and minutes.

Table 6.II(Cont.)

Command	SITE/time	Event
AM113	GDS/40:06:19	Batt 3 - Off
AM043		PCG3 to Reg 1
AM003		SAS3 to PCG3
AM143		Batt 3 DISCH-LIMIT-AUTO
AM103	BDA/40:06:35	Batt 3 - On
AM156	HSK/40:07:26	Batt 6 DISCH-LIMIT-INHIBIT
AM056		PCG6 to Reg 2
AM016		SAS6 to PCG7
AM116	GDS/40:09:36	Batt 6 - Off
AM046		PCG6 - Reg 1
AM006		SAS6 to PCG6
AM146		Batt 6 DISCH-LIMIT-AUTO
AM106		Batt 6 - On
AM158	BDA/40:09:46	Batt 8 DISCH-LIMIT-INHIBIT
AM053		PCG8 to Reg 2
AM013		SAS8 to PCG5
AM118	ACN/40:11:53	Batt 8 - Off
AM048		PCG8 to Reg 1
AM008		SAS8 to PCG8
AM032		PCG8 - Off
AM108		Batt 8 - On
AM015		SAS5 to PCG6
AM017		SAS7 to PCG8
AM115		Batt 5 - Off
AM117		Batt 7 - Off
AM141		Batt 1 DISCH-LIMIT-INHIBIT
AM142		Batt 2 DISCH-LIMIT-INHIBIT
AM143		Batt 3 DISCH-LIMIT-INHIBIT
AM144		Batt 4 DISCH-LIMIT-INHIBIT
AM141		Batt 6 DISCH-LIMIT-INHIBIT
AM155	GWM/40:12:27	Batt 5 DISCH-LIMIT-INHIBIT
AM055		PCG5 to Reg 2
AM028		PCG8 - On
AM105		Batt 5 - On
AM115		Batt 5 - Off
AM157	GDS/40:14:30	Batt 7 DISCH-LIMIT-INHIBIT
AM057		PCG7 to Reg 2
AM107		Batt 7 - On
AM117	VAN/40:16:32	Batt 7 - Off
AM195		ATM1/XFR 1 Close
AM196		ATM2/XFR 2 Close
AT088	VAN/40:18:10	C&D Logic Bus 1 - Off
AT095		TM Bus 1 Off
AT082		C&D Logic Pwr On
AT094		TM Bus 1 On
AT088		C&D Logic Bus 2 Off
AT087		TM Bus 2 Off
AT096		TM Bus 2 On
AT088		C&D Logic Bus 1 Off

Table 6.II (Cont.)

Command	SITE/time	Event
AT087		TM Bus 2 Off
AT096		TM Bus 2 On
AT088		C&D Logic Bus 1 Off
AT061		CBRM 1 Chgr Off
AT021		Reg Off
AT062		2 Chgr Off
AT022		Reg Off
AT063		3 Chgr Off
AT023		Reg Off
AT064		4 Chgr Off
AT024		Reg Off
AT065		5 Chgr Off
AT025		Reg Off
AT066		6 Chgr Off
AT026		Reg Off
AT067		7 Chgr Off
AT027		Reg Off
AT068		CBRM 8 Chgr Off
AT028		Reg Off
AT069		9 Chgr Off
AT029		Reg Off
AT070		10 Chgr Off
AT030		Reg Off
AT071		11 Chgr Off
AT031		Reg Off
AT072		12 Chgr Off
AT032		Reg Off
AT073		13 Chgr Off
AT033		Reg Off
AT074		14 Chgr Off
AT034		Reg Off
AT075		15 Chgr Off
AT035		Reg Off
AT076		16 Chgr Off
AT036		Reg Off
AT077		17 Chgr Off
AT037		Reg Off
AT078		18 Chgr Off
AT038		Reg Off
AT095	VAN/40:19:49	TM Bus 1 Off
AT097		TM Bus 2 Off
AM193		ATM1/XFR 1 Open
AM194		ATM2/XFR 2 Open
AM038	ACN/40:20:04	PCG8 - Off
AM034		PCG4 - Off
AM036		PCG6 - Off

Table 6.II (Cont.)

Command	SITE/time	Event
AM078		Chgr 8 - Bypass
AM074		Chgr 4 - Bypass
AM076		Chgr 6 - Bypass
AM118		Batt 8 - Off
AM114		Batt 4 - Off
AM116		Batt 6 - Off
AM111		Batt 1 - Off
AM113		Batt 3 Off
AM011		SAS1 to PCG2
AM013		SAS3 to PCG4
AM032		PCG2 Off
AM112		Batt 2 Off

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APPENDIX 7

Crew Debriefings.

I. Description. Following splashdown of each manned Skylab mission, each crew held two separate debriefings. The first was a self-debriefing which followed a specific outline with no questions. The second debriefing was a Systems question and answer session, with the questions developed by MSFC. The pertinent crew comments are summarized in the following paragraphs:

A. SL-1/2 Self Debriefing. Pertinent comments were provided by Joe Kerwin.

B. SL-1/2 Systems Debriefing. Comments were provided by Pete Conrad, Paul Weitz, and Joe Kerwin.

C. SL-3 Self Debriefing. Comments were provided by Al Bean, Jack Lousma, and Owen Garriott.

D. SL-3 Systems Debriefing. Comments were provided by Jack Lousma, and Owen Garriott.

E. SL-4 Self Debriefing. Comments were provided by Bill Pogue, Jerry Carr, and Ed Gibson.

F. SL-4 Systems Debriefing. Comments were provided by Bill Pogue and Jerry Carr.

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A. SL-2 CREW SELF DEBRIEFING

KERWIN:

Electrical Power System. The ground did most of the management on that, God bless them. Some confusion still remains in my mind as to exactly what was going on in one or two of the CBRMs, and why we had lights at given times. But I think those are details, and the fact that the ground handled the power system with very little assistance required from the crew simply allowed us to forget most of what we knew about EPS malfunctions in the ATM.

SWS Parallel Power. Again, the ground handled paralleling and had us set the transfer bus voltages pretty much by rote, from time to time, to keep the paralleling to where they wanted it, and that worked out very well.

Controls and Displays. I think the controls and displays are very awkward on the ATM in terms of malfunction detection in the CBRMs. The business of alert light, talkback, switch position, talkback going gray going back to barber pole, not going gray when you powered the thing down--if there was more than one CBRM that was having a malfunction, the light would stay on. That's a complicated, cumbersome system, and I hope we won't design one like that again. It contributes to my own present mental confusion as to exactly what the status of the CBRMs was at all times. It looks like it would be easier just to tape up those alert lights that go on all the time so you can use those alert lights for some objective.

We taped up two of them. We didn't tape the BAT CHARGE light. I guess we always hoped we were going to get through that one, but we didn't. We did put a piece of red tape over the DOOR OPEN light and the POWER SYSTEM ALERT light. We still had the BAT CHARGE light on most of the time.

Lighting Subsystem. The only comment I have on ATM lighting is that we never used the integral lighting on the ATM except for pointing a couple of times. The ambient lighting of the ATM is adequate to do the job. It's not as bright as you'd like to have for reading and writing, but if you made it that bright, it would be too bright for good observation on the monitors. So, we generally operated with two MDA lights on in the vicinity of the ATM panel and that's all. The integral lighting, under those conditions, was simply not necessary. It's beautiful lighting, but it's not required. One comment on the controls and displays that Paul and I noticed. Under the lighting conditions we had, it was very difficult at times to tell a gray talkback from a white talkback. If you see first one, and then the other, the ambiguity goes away;

but if you look at a gray talkback, you're very likely to think it's a white one, if you don't see a white at the same time. And I think in the future we should avoid those two colors on the same talkback.

The brightness of the numeric displays on bus 2 (fixed) was not uncomfortable although it was brighter than we would be running once we got our variable lighting back. There is some brightness authority available when you set the thing to comfort level; not a lot, but some. I mentioned in the technical debriefing that the brightness of the display of the numerics did not appear to decrease noticeably to us over the course of the mission.

B. SL-2 CREW DEBRIEFING - ELECTRICAL SYSTEM QUESTIONS AND ANSWERS

SOLAR ARRAY

1. How close did the CSM fly by the ATM Solar Array?

About 35 to 50 feet above and aft, - one time.

2. Give a general description of the wiring remaining at OWS SAS Wing 2 root. Was the wiring cut clean or were many wires dangling?

Wiring was torn--fragments extend 2 to 4 feet from OWS.

3. Was there any damage observed to the solar cells on the outboard panels of each wing section of OWS SAS Wing 1 after deployment?

Flyaround showed no visible damage.

LIGHTS (General/Panel)

4. Are any instrument panel status lights inoperative?

All status lights on 200 panel were operative.

5. Were all docking and EVA lights operative?

All lights operative.

6. How many, if any, 10 and 20 watt tunnel or STS handrail lamps required replacement? Were there any replacement problems?

One handrail light was and is out--no attempt was made to replace.

7. Was the lighting range provided by the AM light dimmer controls adequate? Comment on the effectiveness of varying the lighting range under the constantly changing external light sources.

Dimming control seldom, if ever used. Handrail lights used for most applications.

8. How often was the lamp test performed? How many failures?

Routine lamp test per time line. No failures on 200 panel.

9. Were there any failures or flickering of general illumination lights?

No failures. There was some transient flickering that was noticeable only if looking directly at fluorescent bulb.

MISCELLANEOUS

10. Was any problem encountered with static discharge?

None.

11. Why did you perform the power transfer function on dark side of orbit?

No predetermined reason for timing. Ground said, "Transfer when ready" so they did without any consideration of orbital position.

WIRING HARNESSES AND INSTALLATIONS

12. Any comments on any electrical equipment or wiring thereto that appeared to be an annoyance or hindrance to movement in the Workshop?

No problem or comments.

13. Was any excessive fraying or damage observed to fiberglass cloth covers on wire harnesses at penetrations in floor and other areas?

No problem. One OWS wire bundle was located too conveniently for handhold and eventually slipped outside tubing off of the fitting. Repair accomplished without incident. No further problem as they stopped using wire bundle as handhold.

14. Did convoluted boots come loose from any exposed connectors in the Workshop?

One incident -- item 13 above.

15. Any difficulty with the electrical connectors for the food trays or the urine centrifugal separator?

No problem.

16. Was the clearance adequate for mating/demating of connectors on the intercom boxes?

All units used were adequate.

17. Were any fans ever operated at high power?

After SAS deployment, many combinations were used--all coordinated with ground control.

CONTROL & DISPLAY

18. X-Ray Activity History Plotter:

a. Review events prior to discovery that the History Plotter paper was jammed.

Problem was crew induced by rolling paper back too far to a known tear and the torn part jammed.

b. What action was taken to verify the Plotter would not operate?

Obvious--tear was visible.

19. Did any crew member have problems with toggle circuit breakers other than the ones on STS panels?

No--problem was primarily with foot operation.

20. Has the brightness of the C&D numeric displays decreased significantly?

Yes--on ATM panel, "Frames Remaining Counter" particularly--"100's very dim on "1". This degradation was expected.

21. Were the flare alert and event timer tones audible in the MDA and OWS?

Yes--MDA can be heard in OWS--(flare alert); OWS flare alert left off.

22. Does the control philosophy utilizing momentary switches with position feedback provide adequate control?

All were OK for the tasks assigned.

23. Were the circuit breaker/switch guards adequate?

Not in the STS--at least a learning curve was required, with control of feet a problem.

24. Were there any problems with Zero-G connectors? For future design do you recommend changing any non-Zero-G connectors to Zero-G, or vice versa?

No failures or any connectors--this crew did not like such a variety of connectors. Standardization is highly desirable, Zero-G undesirable particularly preattach alignment requirement.

25. Did any of the electrical panels or equipment present a touch temperature problem?

OWS panels were hot on the sun end, vacuum cleaner blower was known "hot" items, but had adequate protection for application.

26. Discuss the legibility of panel marking and switch/circuit breaker nomenclature under lighting conditions encountered during the mission. Contrast early mission (reduced lighting) with post OWS SAS deployment periods.

Couldn't read STS during (pre-deploy) early mission on ambient light. Legibility is OK if light is available.

27. Was the nomenclature adequate for identification/understanding of intended control functions?

Training eliminated mission difficulties. Could not change hardware once it was built.

28. Were there any nuisance circuit breaker trips?

A few in beginning of mission, mostly by "foot trip"--the check-out proved OK. No electrical tripouts recalled.

29. Was any difficulty encountered when required to position switches/circuit breakers on a panel and observe system response on a display on a difficult panel?

None recalled--one problem with lights on S073 during sleep period. With all lights possible turned off, crew had to rig guards to dim lights on remaining 4 to get sleep.

30. Is identification and grouping of frequently used switches/ circuit breakers adequate to preclude inadvertent operation of adjacent circuit breakers or switches?

Some on ATM too tight--(too many controls in too small an area) Also, STS had to many C/B's on a panel - parallax is a problem and resulted in inadvertent "off" operations.

31. Assess the adequacy of onboard displayed instrumentation for ranges and banding of meters.

Direction of current flow to/from CSM confusing, particularly since ground and flight displays for CSM volts did not agree--some problem in reading low scale values on high range meters--(CSM amps typical).

LOAD MANAGEMENT

32. How long was vacuum cleaner used each operation?

About 15 minutes for screen cleaning, spread over 1/2 hour (Over 3 day period)- - the blower in shower about 1/2 hour; suit drying 30 to 40 hours per usage.

33. Was vacuum cleaner used in MDA or AM?

Used in OWS and MDA, didn't recall AM usage.

34. Were high intensity lights used for photography or TV? If so, when?

M151 and S073 as defined in flight plan.

35. Was video tape recorder standby power on continuously? Was all color TV recorded?

In early mission, panel switched per ground instruction to conserve power. After SAS deploy - operated per flight plan.

36. Were any general illumination lights left on continuously during the mission--especially during sleep periods?

No--all lighting down eventually--flashlights considered adequate for orientation during sleep periods.

37. What general illumination lights did you turn on routinely upon awakening?

No standard pattern.

38. When did you turn on the waste processors each day?

Twenty-eighth day of manned mission was first use.

39. Were food tray timers used to sequence the cavity heaters for the meals?

Not until after day 14 - (used 45 minutes, on manual). Used timers for 1.5 hours maximum (not 2.5 hours) after day 14.

40. How long before each meal were the food tray cavity heaters activated?

About 1.5 hours heating before heating--thawed in ambient.

41. Did any equipment operation require the use of any support equipment (such as vacuum cleaner, portable fan, high intensity light, etc.) not identified in the checklists?

Checklist 99 percent OK--No routine oversight.

CAUTION & WARNING

42. In the crew's opinion, were the number of Caution and Warning parameters monitored adequate?

Performed well--alarms received were input problems. Sufficient coverage; rapid Delta P had deficiencies in mission rules. No omissions known in STS/AM. CBRM still confusing. Didn't like control scheme. Ambiguous C&W: couldn't clear (inhibit) perm. failure--taped lights--talkback on "bat low" (ATM should be like AM).

43. Would you recommend retention of both Caution and Warning parameters/alarms for future design or would a single "Alert" function be satisfactory?

Human factors considered--Pete prefers different tones--Do react differently to "Caution" & alarm.

44. Were the audio levels of the Caution, Warning, and Emergency tones adequate throughout the vehicle? What was the desired setting on the C&W volume controls?

Adequate--left at launch setting.

45a. Were there any difficulties encountered when replacing a fire sensor assembly or fire sensor control panel?

No.

45b. Was the procedure followed and was it adequate?

Yes.

46. During the second EVA on DOY 170 the AM AFT compartment fire sensor inhibit switches on Panel 207 were "inhibited." Did sunlight activate FSA 392-2? This would be indicated by the appropriate light on FSCP 392.

Also inhibited inputs to fire sensor -- system died during EVA-precautionary to prevent burnout of box (Bus 1 and 2 sws off on 392-2).

47. During the second EVA which panel was used to activate the SUS pumps? If panel 317 and/or 323, did the C&W Delta P warning parameter go off?

Per checklist/timeline -- no warning.

C. SL-3 CREW SELF DEBRIEFING ELECTRICAL POWER SYSTEM

BEAN:

They did all these battery checks which were simple enough, except they were time consuming. We can do those if it's necessary.

LOUSMA:

I felt that I was being employed in the busywork operations from time to time on this battery check, particularly when you checked the same battery that you checked a day or two before.

GARRIOTT:

Everybody knows how those things are working and the flight controllers can give them a better briefing on that than we can. I think they ought to have a briefing on the way the battery tests run, how the ground is discharging the various CBRMs and determining their state of charge and their charge capacity. We had not had any of those briefings prior to launch and so had to figure out from the teleprinter info that came up. They should get a good thorough briefing on the EPS and all of the tests that are contemplated.

BEAN:

Want to say anything about that funny you had, Owen? That went away and never came back?

GARRIOTT:

Well, it was reported on the down-link and I presume that we're talking about the one where we changed the CBRM selector switch. When we rotated to the new position, as I recall, both the chargers and the regulator kicked off, all three, and batteries. I forgot whether they all kicked off, but I think they did.

BEAN:

That's what I remember.

GARRIOTT:

It was never repeatable after that. Although I thought the ground had some vague suggestion as to what it might have been. Some sort of a transient in there. It happened on one occasion. I flipped it twice to make sure that it wasn't just two different CBRMs. So it wasn't just my imagination, and I don't know any other explanation at this point for it. There was normal operation after that, I know of no other problem.

BEAN:

Power Distribution; Buses, Shunt Regulators, Cround System; Power Transfer; Control and Displays: You might want to say something about ATM at this moment.

GARRIOTT:

We have a problem with turning power on both ATM TV buses simultaneously.

GARRIOTT:

You somehow power up both buses at the same time when you throw the sync gen switch. An to avoid that, we're just using ATM TV Bus 1, as I understand it. And the ground is essentially doing that for us. We have a piece of tape over the sync gen switch. Apparently this is the way we want to continue to operate in SL-4. And we also have some problems with the AC buses. But I would rather get the EPS experts to try to explain that problem and not try to do it without having had a chance to talk to the system experts first, and at this point we have not yet had a chance to talk with them. We may only have one AC bus available, instead of two. Can you add anything to that, Jack?

LOUSMA:

Negative.

GARRIOTT:

So, the story I've just given you has some reservations as far as accuracy is concerned. I'd like for you to talk with the ATM experts before really getting a clear explanation together to give to the next crew.

LOUSMA:

As far as operating all the electrical power system, instrumentation and all that, the recording and so-forth -- the ground handles all of that and occasionally they'll come up for a request to adjust the pot or something like that, but other than that, it's all ground control. I'm glad it is, because there are too many other important things to do. It was very satisfactory arrangement, I think.

GARRIOTT:

They can do such a much better job of it anyway, because they can monitor real time, monitor telemetry, look at it continuously, and find any glitches that show up, and they're just far better equipped for it.

LOUSMA:

You seldom find yourself doing anything to that whole system. An occasional glance, maybe, to see how the batteries are doing, for your information, but other than that, the ground takes care of all that.

GARRIOTT:

ATM Alert Light Subsystem: We had one light taped. I think it's the bat charge alert light. SL-2 crew left it taped and we never took it off.

ATM Lighting Subsystem: Now, there is some stuff on the lighting, but I don't think we're the best ones to describe which of those buses are available and which ones are not. With the present panel configuration, we leave the numeric integral in the fixed positions. We never go to variable. That's because of the availability of certain buses and problems on the other buses. And I'd rather not try to describe that and get it mixed up. I'd rather get the ATM people to give SL-4 a good briefing on it.

D. SL-3 CREW DEBRIEFING - ELECTRICAL SYSTEMS QUESTIONS AND ANSWERS

CONTROLS & DISPLAYS

1. Any general comments about physical arrangement of switches/ circuit breakers and identification of systems on the control and display panels?

I'm glad that the design includes switch guards. We did use circuit breakers for switches. In some cases, the checklists call for circuit breakers and in some cases, switches. There seems to be a randomness between use of circuit breakers and switches.

2. Assess legibility of panel markings and switch/circuit breaker nomenclature under lighting conditions encountered during the mission.

Adequate.

3. Switch/circuit breaker grouping versus tasks:

a. Was any difficulty encountered when required to position switches/circuit breakers on a panel and observe system response on a display on a different panel?

Some operations required a two-man operation, however, this did not present a problem. Examples are: 1) dump heater switch in the wardroom and the light in experiment compartment; 2) fire sensor panel in the STS and sensors in the OWS.

b. Is identification and grouping of frequently used switches/ circuit breakers adequate to preclude inadvertent operation of adjacent circuit breakers or switches?

Adequate.

4. Assess adequacy of on-board meter ranges and color banding.

Adequate in most cases. Bus amps (in the OWS) did not have the proper resolution for accuracy.

5. Did any circuit breaker nuisance trips occur?

None in the OWS. (ATM AC circuit breaker for Inverter Lighting tripped a couple of times. Reported on air-to-ground, Channel A.)

6. Assess adequacy of solar flare alert panel (607).

Hardly ever used because someone was normally at the ATM C&D panel.

7. Assess adequacy of guards to prevent inadvertent operation of switches or circuit breakers. Were any problems encountered with the guards and the related finger clearance?

We may have initiated a Fire Detection test switch checkout when attempting to clear a master alarm. Was reported on air-to-ground at the time.

8. Were there any failures when lamp tests were performed?

No.

9. Were any problems encountered because of proximity of rotating litter chair to the power and display console?

No.

LIGHTING

10. With regard to 42 lights installed in OWS assess adequacy of general illumination levels in each compartment.

Reported during the mission as one part of M487. In general, the lighting was not bright enough. Close work required the use of a flash light. Lighting was best in the wardroom and worst in the WMC.

11. Assess adequacy of control of illumination levels via control panel switches and light integral switches.

Difference between bright and dim levels was very slight. Used them on either high or off.

12. Did any general illumination bulbs fail? Any flicker?

Don't recall replacing any OWS lights. Replaced a few (12) small bulbs on the STS hand rail. Some of these were left on all night. They would begin to get dim prior to burning out.

13. Assess adequacy of illumination of the C&D panels.

Adequate in the OWS. The panel lights were required in the STS and were used when required. The electroluminescent lights were used on the ATM C&D console.

14. If portable lights were used, any comments on ease of usage or light output?

Al used one in the sleep compartment because he turned his bed around to improve the ventilation. It was a permanent installation.

15. Assess adequacy of portable high-intensity photo light. What operating modes were used?

In general, they were used per the checklist, however, they were used as required. Jack remembers using it once on the wardroom table.

WIRING HARNESSES AND INSTALLATIONS

16. Any comments on any electrical equipment or wiring thereto that appeared to be an annoyance or hindrance to movement in the Workshop?

No.

17. Was any excessive fraying or damage observed to fiberglass cloth covers on wire harnesses at penetrations in floor and other areas?

No.

18. Did convoluted boots come loose from any exposed connectors in the Workshop?

No.

19. Any difficulty with the electrical connectors for the food trays or the urine centrifugal separator?

They worked good.

20. Was the clearance adequate for mating/demating of connectors on the intercom boxes?

Yes.

21. Were any problems encountered in mating/demating Zero-G connectors?

No.

22. Assess crewman's ability to mate/demate non-Zero-G connectors.

A couple were a little tight (molesieve, LBNPD). All types of connectors were acceptable; Zero-G, microdot, bayonet, etc.

MISCELLANEOUS

23. Assess utility outlet adequacy, accessibility, number and location.

Never used the ones in Waste Management Compartment. Could use two more in experiment compartment and two more in MDA.

24. If any lights, intercom boxes or heaters were replaced, any comments on cause or problems?

Replaced one SIA and the dump heater probe. No problems.

25. Was any problem encountered with static discharge?

Owen remembers one time he could feel static electricity in the hair on his arm while getting dressed one morning.

26. Was the "OWS TCS CHECK", ref. SWS SYSTEMS CHECKLIST, Sheet 9-18, ever performed during the mission?

This is HK70V. Can't recall performing and EGIL does not recall requesting the performance. Pre-mission concern was expressed about noise from fans. It is difficult to determine if they are running even when you are in the same area.

27. How many 10 and 20 watt AM light bulbs burned out and required replacement? (Note: on SL-3 DOY 221, it was reported that three 10-watt STS light bulbs were replaced.)

See question 12.

28. As a result of troubleshooting the MDA aft 2 and 4 lights, it was reported that the toggle switch was intermittent. How was this conclusion arrived at?

The switch was turned on one day and lights didn't come on; the next day when turned on the lights came on. Therefore, it was reported as intermittent. After the lights came on, the switch was taped and the lights were operated using the switches on the lights.

29. Could you expand the description of the AM PCG battery capacity discharge test? Did the current rate control require constant input? Was there any unusual/unexpected behavior, glitches, etc.? Did the fine adjust pot adjustment utilize the full travel in either direction?

The first one required constant adjustment in keeping within limits. After talking about it on the air-to-ground, it was understood that constant adjustment was not required. On subsequent tests the adjustment was made to the specified setting and not adjusted again. The ends (stops) of the rheostat were never reached.

30. Are any AM power system status lights on panel 205 burned out?

All are working.

31. Were the battery control circuit breakers opened during deactivation?

They were left open.

32. During fly-around prior to leaving Skylab, did you notice any discoloration on the back surfaces of the ATM solar panels? If so, to what extent?

Didn't do fly-around. Undocked at night and could not see.

33. Describe to the best of your recollection the anomalies associated with the ATM C&D panel with respect to the power control section of the panel.

ATM or EGIL should have a complete list. All management was done from the ground. Jack was not impressed with the Alert system. He got used to seeing the blue light on and did not respond to the ATM alerts.

34. To your recollection, were there any times during the mission that CBRM 18 was selected other than during CBRM BAT 18 capacity testing?

Most certainly. At various times all of them were selected. Do not recall seeing ATM Bus 1 low light on. If there was one it would have been reported on air-to-ground.

35. Was the original problem on I/LCA variable lighting on DOY 214:22:25 encountered while operating on variable bright control or did variable lighting fail to come on when turned on?

Have been using variable as the normal routine. Can not recall for sure, but think it was noticed when we came to the panel one morning. The switch would have been in off and then switched to variable.

C-4

36. How was the mating and demating of the NB connectors used on the rate gyro 6-pack, compared to the zero-G and Microdot connectors used throughout the cluster?

It is easier in Zero-G than in One-G. A tool is used sometimes to get the alignment more precise.

37. Were the MDA light filters for aft lights 3 and 4 required while operating the ATM C&D?

No. We forgot about them. The lights were turned off instead of using the filters.

POWER MANAGEMENT

38. How long was the vacuum cleaner used each operation?

Five minutes.

39. Was the vacuum cleaner used in the MDA or AM?

Used to clean three screens, with two-length extension cord.

40. Were the high intensity lights used for photography or TV? If so, when?

See question 15.

41. Was the Video Tape Recorder standby power on continuously?

No.

42. Was all color TV recorded?

Per checklist.

43. Were any general illumination lights left on continuously during the mission, especially sleep periods?

All in OWS were off. Handrail lights in STS were on.

44. What general illumination lights did you turn on routinely when you woke up every morning?

All OWS lights.

45. When did you turn on the waste processors each day?

As required.

46. Were the food tray timers used to sequence the cavity heaters for the meals?

Always.

47. How long before each meal were the food tray cavity heaters activated?

Longest--1.5 hours.

48. Did any experiment operation require the use of any support equipment (such as vacuum cleaner, portable fan, high intensity light, etc.) not identified in the checklists?

No.

49. What is the difficulty in turning off loads when required for EREP and Anomalies? Loads such as H_2O Heaters (WMC, Wardroom); C&W Redundant Loads; ILCA Heaters; OWS TCS Monitor; OWS Duct Heaters; OWS Lights, MDA & AM Lights.

None--sometimes the MDA lights were not off-loaded as they were needed to read the checklist. Usually, we off-loaded OWS lights to compensate.

E. SL-4 CREW SELF DEBRIEFING ELECTRICAL POWER SYSTEM

CARR:

I, quite frankly, never had any difficulty coping with the solar array system in training and I felt that I had grown to understand it and it was a reasonable, straightforward system.

POGUE:

The only comment that one could make on these power conditioning groups and the CBRMs is that they ought to be accessible from inside the vehicle, because we could have performed all kinds of maintenance if we could have gotten to the connectors, etc., from inside. Now, don't ask me how to do it, but that sure caused a lot of trouble.

GIBSON:

Yes, I think that's a real good point. We had problems with the ATM and, if we had been able to get to them, I'm sure we could have done a much better job.

CARR:

I think being able to get in and change things like voltage regulators and things like that would certainly have simplified a lot of their problems. If we would have just had access to go on in and change the voltage regulator that's giving you trouble or a battery charger, things would run smoother.

GIBSON:

Well, we at one time, were talking about a task EVA which would allow you to get solar array power from one unit over to another CBRM, and, had we been able to do that EVA, I'm sure we'd have done it right away and gained a little extra power. As it turned out, we didn't really need it because we had a little extra power in the system, but we're always better off designing it so you can get to it. In terms of the whole power system, I found that I thought I was overtrained for it. I spent an awful lot of time over there in the simulator working with bus shorts and all kinds of problems which I would never encounter in flight, because I was never sitting right in front of that panel watching things happen. I thought that in flight, I had negligible interface with that system, whereas I really trained a lot on the ground for it.

POGUE:

It was an interesting and intriguing system, and that's one of the reasons that we all three spent more time on that than we needed. However, I've looked into that system and I think that there are several lessons to be learned from the design. One is that when we mentioned the bus short, there were certain people in the design business who felt that we were questioning their integrity personally. But the point was made that you could not experience a bus short in Skylab. We were handed pieces of the buses encased in some plastic and told this thing can't short. Well, of course, what we meant was it doesn't make us any difference whether that piece of metal shorted or whether a wire from that bus shorted. To them, it was a matter of professional pride, and certainly there was a misunderstanding there for a long time. The point is, that we did have bus shorts in flight, and we were guaranteed prior to that, that there was no way to short out one of those buses. However, we did train for bus shorts.

Now, the CBRM, and the PCG systems--I did not feel that there was sufficient controllability over the configuration in either one of these two to protect yourself against an uncontrolled short and to take maximum advantage of the power-generating capability that you had. I think that this would not be a satisfactory system for going to Mars. We do not have enough control over this system in isolating shorts, and we did not have enough control over this system to take advantage of a perfectly good solar panel group which might have to be isolated because it was feeding a short.

GIBSON:

That's a good point. I remember the problems that I could picture us getting into and we actually did get into some with the CBRMs. I would think we ought not only to be able to transfer power from one solar array over to another CBRM but also be able to replace those components which are bad. And that goes back to our original plan of being able to get to it all.

POGUE:

We did not have complete--satisfactory monitoring of the status; we had to pull all kinds of shenanagans to isolate bus shorts in training.

CARR:

An example of the areas you were talking about was when we had a collapsed solar array; it had such a draw on it that it finally collapsed. We didn't know that; we had to ask the ground that kind of question.

POGUE:

Also, the indicators, when fed a real heavy short would reverse themselves and start indicating all over again, stuff like that was biting us, and that's the sort of thing that you want to avoid.

CARR:

Power Distribution: The only area here is the shunt regulator which was always a mystery. It took a long time to understand what a shunt regulator was and I wonder if that wasn't something that could have been dealt with differently in the design and made more clear. It just killed us in training to have to throw away a whole solar array group, because what it was feeding was bad and there was no way to move it to something else and take advantage of that power source. Maybe access to go down and put jumper plugs in somewhere would do it.

GIBSON:

ATM Electrical Power System: We let the ground do most of that. We've already touched on the electrical power system for the ATM. There were the problems of being unable to get to the CBRM to make mechanical repairs and being unable to allow one solar array to go through another CBRM, which would have been desirable.

GIBSON (continued):

ATM Control and Displays: These were a nightmare to interpret where there was a fault in a given system or whether there was a DAP problem or low voltage. This troubleshooting onboard required extensive chasing around through rotary switches and two- or three-position switches.

That was an exceptionally cumbersome system to work and if we had it to do over again, we would have designed it differently. We worked ourselves into a corner when we guaranteed that there was only going to be one CBRM failure and then we could in no way inhibit any of the fail inputs into the logic which controlled those controls and displays. It was very evident throughout the Skylab mission, that we would have been better off if we had had a parameter inhibit capability, a thermal control subsystem. It all worked well and we never had any reason to be working with that system at all. If you do start having problems, however, you might get involved with those controls and displays and a little bit more.

ATM Alert Light Subsystem: I found that the alert light occasionally comes on and you never notice it, so we did have a slight problem. If you were looking for something like a scan spect alert light, which I was on occasion, you would see the alert light come. But there were a few times that I mentioned before when we had S055 tripouts that the scan spect alert light came on. It went unnoticed for a period of time then all of a sudden I noticed that we had a different alert light on than we had before. I would rather have some type of a tone associated with that to call attention to the fact that something changed. The visual cue at the top of the panel was not enough.

Lighting Subsystem: On the ATM panel I was sorry to see that we had to operate in the fixed mode on two out of the three controls. It took away some of the flexibility I would liked to have had. The variable mode was useful, and it should be designed into the future control and display subsystems. Lastly, we lost the integral lighting I found that before we flew I was somewhat of a skeptic on the utility of the integral lighting, I felt that it was a nice thing to have, but not mandatory. However, I was no longer a skeptic after we lost it because in the darked atmosphere in which we were working, it was quite difficult at times to read the panel, and some mistakes were associated with not being able to read the panel. I still forgot the nomenclature on switches as well as I knew that panel nomenclature. That is needed on future C&D systems where you plan to work in a darkened atmosphere which we certainly did on the ATM.

CARR:

Lighting System: I thought the MDA lighting was more than adequate and you could pretty well set up almost any way you wanted to.

GIBSON:

I found that we were continually changing the configuration of the lighting around the ATM. Each of us liked it a little different way. I like it relatively dark and the other guys liked it relatively light and we were forever changing those lights. Even when you're working at the panel you'd find the need to see something on the display a little better and you would have to leap off of the foot restraints you were in and turn off a couple of lights. In that circumstance, I would have liked to have had control of the lighting around the ATM right at the ATM panel itself.

POGUE:

I covered this in an M487 debriefing, but I think that there is the case to be made for various and sundry types of dark curtains and shades, much as radar men use when looking at scopes. It would have been nice if there was something like that around ATM. This may affect the ventilation. I think, however, that there is a way of handling it. It would have been good to have a double curtain at the MDA forward hatch for the commentary photographs. Of course, no one knew ahead of time that we were going to be using those windows.

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CARR:

In the Airlock Module area, the lighting was more than adequate. You had selectable, bright or dim, and I had no complaint with airlock lighting. I did notice that light bulbs were inclined to plate out. Apparently, the filaments would plate out on the inside of the glass of the bulb and pretty soon your light bulb that started out nice and bright, would get very dim and you'd have to change it out. I completely changed out the bulbs in the aft airlock one day because the lighting was getting so dim.

POGUE:

One of the things that bothered me a little bit about those incandescent bulbs was the covers. I know they were supposed to slide off but they were always getting knocked free. I would like to have a little more positive snap shut feature on those things so they wouldn't always come loose.

CARR:

In the workshop area, lighting was easily controllable and quite adequate. You could go from bright lighting in the dome area and the forward compartment to very dim lighting or no lighting, whatever you wanted. There didn't seem to be any great problem. One area where we did run into a few problems was when somebody using the antisolar airlock needed to have it dark. It meant that the whole workshop had to be darkened because one of the disadvantages of the grid floor was that it also lets light as well as air come through. We had to turn off the lights in the wardroom and the experiment compartment, and everyplace, in order to get the forward compartment dark enough for dark adaptation for some of the experiments we were doing. This again is a good case for the idea that Bill proposed of hoods. It would have made it possible for a crewman to do a scientific airlock experiment without having to turn off every light in the house.

POGUE:

Before I forget, we need a wristwatch that has a real good night dial light. After the lights went out, the Accutron dial went out, too. We couldn't really use it in the dark.

Counter argument to that would be that the experiments were all ad hoc. I'll never see the day coming where we will not have ad hoc experiments. There will always be that last item that's thrown on board, where you do everything manually. We do need a good night wristwatch.

GIBSON:

Going back to the problems of the SAL: I think Bill proposed a reasonable idea with a hood. Two problems that we ran into there: one was the case where you need complete darkness, as in the S063 looking at the airglow, for example. You'd find that the record light on the opposite SIA would show up in the field-of-view and reflect into the instrument; something that small would interfere with the operation. Having a hood surrounding the whole thing would have eliminated that problem.

Another problem I encountered when running S063 on the day side, was I wished that I had a small night light right next to the SAL, which I could have used to shine on the checklist and the pad. I would operate the S063 ozone instrument, look out in the Sun, down at the Earth, and then try to look back in and look at the pad and found out that I was completely blinded because I had nothing but sunlight coming in my face. I couldn't read it. I finally had to tape a flashlight, which I ran down during the course of two or three orbits. I don't think that was the way to go. I think we needed a little night light at the SAL's as well as something we may get to later, which would be a checklist holder.

CARR:

Lighting in the wardroom, the sleep compartments, in the experiment compartment.

POGUE:

Experiment T002 could have been performed in the wardroom if we'd had a way of blocking off light other than that enormous hood that they had, which was much too complex. That's not the way to go. We had a shade door on the wardroom and it was translucent. I could have darkened that area pretty well there if that would have been a little less transmissive of light. Partition doors are something to consider in the future. As far as the lighting in the wardroom itself, it was great.

CARR:

Lighting was certainly not one of our problems in crew system. There was plenty of lighting and it was flexible enough so that you could turn it off, if you didn't want it.

F. SL-4 CREW DEBRIEFING - ELECTRICAL SYSTEMS QUESTIONS AND ANSWERS

1a. During pre-docking/station keeping are the 4 lights on the discone antenna visible, and do you think they were necessary?

The discone antenna lights were observed during rendezvous and they are necessary for measuring depth perception at night.

1b. Are all AM colored running lights still burning? (Have any burned out yet?)

The undocking was during orbital daylight so the running lights were not observed. The crewmen recall that there were a lot of lights during rendezvous prior to docking. There were some good films of the rendezvous sequence and a review of these films would be helpful in determining if all the running lights were on at that time.

2. Have any AM EVA lights burned out? What location?

No. Lighting for EVA was excellent.

3. How many 10 and 20 watt AM bulbs required replacement? Any problems encountered during replacement?

The aft and lock compartment lights were replaced because the light level decreased due to metallic plating on the bulbs. Similar plating has been observed in the JSC trainer. Prior to undocking the STS and Forward Compartment lights were beginning to dim due to the plating and were nearing the replacement level. The replacement procedure was simple. The incandescent light covers were always slipping out of position. The crew was surprised that some of the light bulbs were not broken due to impact after the covers slipped out of place. Handrail bulb covers were easily bumped free.

4. Did the tracking lights operate properly?

Yes. The crew expressed surprise that the occulting light made tracking more difficult. The tracking light flashing frequency was too low and did not permit adequate time to acquire and "mark" for tracking.

5. Did any of the status lights burn out? STS Panels 203, 204, 216, 205, 206?

No. The crew kept them off.

6. Which type of connector is preferred for connecting and disconnecting by the crew? (Zero-G, Airlock/Microdot or Bendix with crew assist ring, etc.) Which type is least preferred and why?

The "Zero-G" connector was judged to be far superior to the other types. It was safe and almost impossible to damage the Zero-G due to misalignment. The Zero-G could still be improved but is definitely superior to the other types.

7. Was meter lighting used in STS? Was meter lighting adequate? Is meter lighting considered necessary?

Meter lighting was used in the STS during periods of low light levels such as during comet observations. The meter lighting was definitely required in the lock compartment prior to egress.

8. Were the variable dimming controls provided for STS and meter lighting utilized? Is this a desirable feature to retain?

The variable dimming controls were used by each of the crewmen at some time during the mission. The crew suggests that the status lights for future designs have dimmers in case onboard system monitoring is necessary. Sometimes a very small status light appeared very bright and was distracting requiring that it be taped.

CONTROLS AND DISPLAYS

9. Any general comments about physical arrangement of switches/circuit breakers and identification of systems on the Control and Display panels?

The design of onboard panels should be sufficient to give the operator visibility of the system operation. Panel 225 in the AM is considered an ideally designed panel. The C&W Inhibit Panel was especially difficult to use. See self-debriefing.

10. Assess legibility of panel markings and switch/circuit breaker nomenclature under lighting conditions encountered during the mission.

Always had light available. Crew wanted distinctive marking for light switch. The panel markings and nomenclature did not give the visibility required for system operation from the panel. The crewmen would like to be able to operate the general illumination lights while seated at the C&D panels.

11. Switch/circuit breaker grouping versus tasks: Is identification and grouping of frequently used switches/circuit breakers adequate to preclude inadvertent operation of adjacent circuit breakers or switches?

No. The visibility of the system was not obvious and the nomenclature was ambiguous.

12. Assess adequacy of onboard meter ranges and color banding.

The use of percentage on meters rather than the meaningful parameter (such as, volts, amps, etc.) limited the system visibility because it was difficult to remember the significance of the values. Color banding is encouraged but parallax did present a problem since the color banding was on the cover glass rather than the meter face. A moveable color band would be helpful in areas where a change in the maximum/minimum allowable system parameters was permitted or expected.

13. Did any circuit breaker nuisance trips occur?

No. The Gemini type breakers were easily thrown when using the panel guards for a hand hold. The crew did not especially like the switch type circuit breakers (too fragile). Never closed breaker without concurrence from ground.

14. Assess adequacy of solar flare alert panel (607).

The solar flare alert panel was not used because of nuisance alerts when going through the South Atlantic Anomaly and over Canada. The MDA Radio Noise Burst Monitor was not used for the same reason; nuisance alerts. MDA audible alarm could be heard in OWS.

15. Assess adequacy of guards to prevent inadvertent operation of switches or circuit breakers. Were any problems encountered with the guards and the related finger clearance?

The guards are necessary to protect the panels but they do restrict the visibility of the panel nomenclature. Inadvertent switch thrown-timer in AM.

16. Were there any failures when lamp tests were performed?

No.

17. Were any problems encountered because of proximity of rotating litter chair to the power and display console?

No.

18. The DAS was operated for what uses?

The main use of the DAS was associated with the APCS. Most additional usage was associated with anomalies such as ATM doors and CMG number one. The occasions were few and far between. Dr. Gibson gave a real good in-depth discourse on the operation of the ATM panel on a MD-19 downlink.

LIGHTING

19. With regard to 42 lights installed in OWS assess adequacy of general illumination levels in each compartment.

OWS general illumination lighting was good.

20. Assess ATM adequacy of control of illumination levels via control panel switches and light integral switches.

The variable lighting was not adequate because it all failed and only the fixed lighting was available. Florescent lighting better than incandescent.

21. Did any general illumination bulbs fail? Any flicker?

No. None.

22. Assess adequacy of illumination of the OWS C&D panels.

The OWS panel lighting was fine. Plenty of light was available.

23. If portable lights were used, any comments on ease of usage or light output?

All crewmen used the portable lights during the mission. The only problem encountered was that of finding the cables required. Future designs should include cable caddies with internal locks. All cables should be color coded for ease in cable identification.

24. Assess adequacy of portable high-intensity photo light. What operating modes were used?

The high-intensity photo lights were adequate but quite directional in nature and therefore caused shadows. The light controls were in the back of the light and were difficult to see. The maximum light output was used at all times. The lights provided excellent illumination for photography.

WIRING HARNESSES AND INSTALLATIONS

25. Any comments on any electrical equipment or wiring thereto that appeared to be an annoyance or hindrance to movement in the Workshop?

None of the cluster wiring was an annoyance or hindrance. The cable wires that were annoying were those that the crew had to assemble themselves. During operation of the MDA Multipurpose Furnace, cables had to be connected to the OWS dome outlets. The cables were a hindrance to crew movement.

26. Was any excessive fraying or damage observed to fiberglass cloth covers on wire harnesses at penetrations in floor and other areas?

None.

27. Did convoluted boots come loose from any exposed connectors in the Workshop?

No.

28. Any difficulty with the electrical connectors for the food trays or the urine centrifugal separator?

No. The connector for the urine centrifugal separator was located behind the separator and was difficult to reach. This presented only a minor problem since the connector was only mated once during the mission.

29. Was the clearance adequate for mating/demating of connectors on the intercom boxes?

Two of the intercom boxes were replaced and the connectors were demated and mated without difficulty.

MISCELLANEOUS

30. Assess utility outlet adequacy, assessibility, number and location.

The number of utility outlets was adequate. If the cable caddies mentioned earlier were available the outlets would have been more readily available. (Needed one more on Z SAL.)

31. If any lights, intercom boxes or heaters were replaced, any comments on ease or problems?

None of the heaters were replaced during the mission. One probe was removed and replaced. The crew was prepared to replace the Urine Dump Probe but it was never necessary.

32. Was any problem encountered with static discharge?

Static discharges were never observed. When donning and removing clothing, the hair on the crewman's arms and heads stood up momentarily.

33. Was the "OWS TCS CHECK", Ref. SWS Systems Checklist, Sheet 9-18, ever performed during the mission?

The "OWS TCS CHECK" was never performed unless it occurred during activation.

34. When the Earth Terrain Camera was operated during EREP passes, the OWS bus loads increased more than the amount required for the camera. Can you think of any associated loads that would cause this increase?

The Earth Terrain Camera sounded like a rock crusher during operation. The crew did not know any other reason for the high OWS bus current.

35. How long before each meal were the Food Tray Heaters on? Was any degradation in the Food Tray Heater operation noted during the mission?

Generally, the trays were not used for breakfast and lunch unless one of the crewmen had chili for lunch. Normally, around 4:00 P.M. the crew activated one tray to warm the evening meal for all three astronauts (on High not Auto), then each turned on an individual tray to keep his food warm during the meal.

36. Were the portable circulation fans used during the mission?

One portable fan was installed to blow on the crewman when he was riding the ergometer. This was optional to the crew. One portable fan was installed in the hatch to blow air on the heat exchanger diffusers.

37. When operating the ATM C&D console, was it noticeable if the MDA Wall Heaters cycled?

No.

38. When passing through the AM, was it noticeable when the AM Wall Heaters were on? If so, did they seem to be on continuously?

No. Crew suggested a visual indication of heater operation such as liquid crystal indication - (low or no power).

EGIL

39. Was the Regulator Adjustment an annoyance?

The adjustment of the AM Reg Bus pots was a minor nuisance, especially if a crewman was in the middle of an ATM experiment sequence and had to interrupt it. A moveable scale for re-referencing the pots would have been helpful.

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NASA TMX-64818

APPROVAL

MSFC SKYLAB ELECTRICAL POWER SYSTEM MISSION EVALUATION REPORT

by A. P. Woosley

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

L D Woodruff
L. D. WOODRUFF
Deputy Chief,
Electrical Systems Branch

R. ISE
Manager, JUN 1
Skylab Program Office

fr. J. L. MACK
Chief,
Systems/Projects Office

F. B. Moore
F. B. MOORE
Director,
Astrionics Laboratory